Late Quaternary erosion, deposition and soil formation near Grevena, Greece:—chronology, characteristics and causes

Mount Orlikos limestone ridge near the village of Zakais, Nomos of Grevena Greece

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Declaration

This thesis contains no material which has been accepted for a degree, diploma or any other higher degree by any other institution, except by way of background information and where duly acknowledged in the thesis and to the best of the my knowledge and belief, this thesis contains no material previously published or written by another person, except where due acknowledgement is made in the text.

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March 2005

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Late Quaternary erosion, deposition and soil formation near Grevena, Greece: chronology, characteristics and causes

Abstract

A history of soil erosion, alluvial and colluvial deposition is presented for a small catchment in NW Greece. The role of climatic events, tectonics and human disturbance of the landscape are examined.

A major valley aggradation, named the Syndendron alluvium, was deposited in the valley floor during the close of the last glaciation. The 15,000 – 10,000 cal yr BP period was a time of dramatic climate fluctuations and associated changes in vegetation, fluctuating between steppe and oak woodland. The Syndendron alluvial deposit is associated with significant fires in the mid and upper catchment, as indicated by ash layers and charcoal in soils dated from this time. Regular fires were clearly an important part of landscape modification in sediments and soil deposited after about 15,000 cal yrs BP. The deposition of the Syndendron alluvium may have began as early as 14,200 cal yr BP but more likely was deposited between ca 12,250 and 9,300 cal yr BP (sites C11, C12, C13 and P37). The alluvium buries distinctive charcoal-rich paleosols dated between 14,700 and 14,200 cal yr BP (sites C6, C9 and C19). Debris flow deposits and slope wash from adjacent hill slopes provided the sediment source for the alluvium and slope wash has buried several distinctive late Pleistocene hill soils (sites C11, C12, C19). Alluvial sedimentation and hill slope erosion continued until at least 11,000 cal yrs BP, as indicated by an eroded hill soil at C11 that is buried by the aggrading Syndendron alluvium. Deposition had, however, ceased by ca. 9,300, as indicated by distinct alluvial soils that developed on the deposit (sites C12 and P37). Several colluvial soils dated to about 8,000 cal yr BP (C9 and C17) also cap the alluvium. The Syndendron alluvial event may in part relate to the arrival of humans during the climatic amelioration associated with the late glacial interstadial (Bolling-Allerod interstadials). Certainly there is increased burning of the catchment after about 15,000 cal yrs BP. Palaeolithic stone tools have been found in the catchment and along with others in the Grevena and Epirus regions, indicating humans were present. This period is also associated with colluvial soil deposition on lower slopes (sites C6 and C19). However, after about 12,250 cal yr BP there is a dramatic acceleration in the erosion rate and associated deposition on the
valley floor and lower slopes. While fire appears to be important, a change to drier and cooler conditions, recorded in the Greenland ice cores as the Younger Dryas phase, may have caused denudation between 12,800 and 11, 600 cal yrs BP. The climate change toward wetter conditions after 10,000 cal yr BP and increasing tree cover appears to have led to a more stable landscape indicated by soil development and associated soil creep. However, there have been no Mesolithic sites identified in Grevena, and it is generally a period of low human activity in Greece.

Following the hill slope erosion and deposition of the Syndendron alluvium the catchment seems to have become relatively stable as indicated by the development of moderately deep and well structured fertile black silty clay loam soils on the Syndendron alluvium. This is also supported in the upper catchment, as soil colluvium caps the Syndendron alluvium after 10,000 cal yr BP (site C12), and the stream re-incised the alluvium before 7,500 cal yr BP (site C11). The stream incision and also the arrival of Neolithic farmers in the valley are associated with a series of landslides and debris flow deposits between 7,500 and 6,500 cal yrs BP. In the lower catchment 2 m of fine-textured alluvium buries well-developed dark soils formed on the Syndendron alluvium sometime after 9,300 cal yrs BP. The landslide deposits dating between about 7,500 and 6,500 cal yr BP in the upper catchment contain large (4 x 1 m), intact pieces of highly weathered soil similar in chemical composition to those preserved on the upper slopes and catchment divide. The renewed incision of the Syndendron alluvium may have over-steepened some slopes and triggered landsliding at this time. The large size of the landslides and paucity of charcoal within them may implicate increased seismic activity as a trigger, as occurred during the 1995 Grevena earthquake. Fault displacements have been noted in both the Tertiary bedrock and the upper Plio-Pleistocene sediments within the catchment, although no active (Holocene) fault scarps were noted.

Work in the base of the catchment indicates that the Neolithic impact was generally minor, with 1.5 m of alluvial deposition occurring between 5,900 and about 4,700 cal yrs BP. However, this alluvium was then abruptly buried by over 2 m of slope deposits derived from erosion of adjacent hills at after about 4,400 cal yrs BP. Thin, 0.2m, A/C soils formed on the alluvial sediments during two stable periods each of about 500 years duration, indicating topsoils can develop rapidly in this environment.
Other dark, loamy soil-like colluvial materials begin to be transported down-slope at about 5,000 through to 2,750 cal yrs BP. However, between 2,200 and 1,300 cal yr BP dark greyish-brown calcareous colluvium containing bedrock debris was deposited in depressions and gullies. This hill slope erosion and deposition was associated with the latter phase of the Sirini alluvium, which is the second major Holocene alluvial valley fill. This alluvium is dated near its base to ca. 4,150 cal yrs BP, but the major deposition occurs after 3,100 cal yr BP with 5 m of sediment being deposited after this date. At another site more than 6 m of fine-textured alluvium is deposited after 2,450 cal yrs BP. Sheep/goat vertebrae and bovine teeth (male) were located in two of the alluvial sections and suggest agricultural grazing practices were very well established after about 3,100 cal yrs BP. The Sirini alluvial deposition continues until at least 2,000 cal yr BP as indicated at one site and 1,700 cal yr BP at another. The Sirini alluvial deposition coincides with a series of colluvial deposits on the valley sides dated between 2,750 and 1,390 cal yrs BP. This Sirini alluvial filling appears to be staggered. At one site a distinct alluvial soil separates the alluvium into two phases Sirini A and Sirini B. Re-incision of the Sirini alluvium occurred sometime after about 1,700 cal yrs BP. Thin and incipient A/C soils form on the top of this alluvium supporting its youthfulness.

In the modern valley floor a very young alluvial deposit named the Leipsokouki alluvium occurs 1 - 4 m above the modern flood plain. This alluvial fill has very weakly expressed topsoil development and is largely composed of raw weakly weathered alluvium. It is dated as modern (140 ± 130 cal yr BP Wk 9926) on charcoal taken from the upper fine-textured alluvium in the mid catchment, but elsewhere it contains Ottoman sherds.
CHAPTER 1  Introduction and background

Key aims of this thesis

In the literature over the last 45 years arguments have raged over the role of climatic, tectonic and anthropogenic factors in the widespread loss of soil cover in the Mediterranean region (Judson 1963; Eisma 1964; Carpenter 1966; Judson 1968; Lamb 1968; Vita-Finzi 1969; Butzer 1974; Bintliff 1975; Bintliff 1976; Bintliff 1977; Eisma 1978; Davidson 1980; Wagstaff 1981; Pope and Van Andel 1984; Van Andel et al. 1986; Kraft 1987; Starkel 1987; Finke 1988; Van Andel et al. 1990; Zangger 1992a; Zangger 1992b; Dearing 1994; Ballais 1995; Runnels 1995b; Marathianou et al. 2000; Macklin et al. 2002; Benito 2003; Starkel 2003; Fuchs et al. 2004). It was Butzer (1982) who called for detailed catchment studies to provide comprehensive and accurate sedimentological chronologies to help resolve the likely casual factors. The current study aims to provide such evidence and interpretations.

The study builds on earlier work undertaken by the author in the Leipsokouki valley (Doyle 1990) near Grevena, north western Greece. Doyle (1990) produced a soil map of the valley, an examination of pedological processes and an examination of the modern soil erosion processes. The 1990 work also undertook some radiocarbon dating (seven sites) in an attempt to determine the sedimentation history in the valley. However, the work only provided a limited number of dated sites and each section had only one radiocarbon date. Thus the sedimentary chronology determined was quite limited. It was the desire to better understand the timing of events using key detailed stratigraphic sections, and also the need to determine the age and stratigraphy of a greater number of the deposits that further research has been undertaken. Dating in the current study has utilised up to four radiocarbon dates per stratigraphic section to better bracket the timing of deposition events. The aim was to develop a detailed sedimentary record that could be compared with the new archaeological record and thus determine the causal factors of the landscape change.

Thus the current study had the following objectives.

1) Establish the sequence of sedimentation and soil erosion in the Leipsokouki valley, Grevena.
2) Determine character of the soil and sedimentary materials and where possible determine their likely origins.

3) Establish the processes by which sedimentation and erosion have occurred.

4) Determine the timing of as many events as possible, particularly late Pleistocene – Holocene, as possible.

5) Review possible causes of landscape change e.g., human, climate, tectonics and fire, and establish their temporal occurrence in the late Pleistocene and Holocene.

6) Postulate causes/triggers of the various erosion and deposition processes in the valley and beyond.

The current research provides 26 radiocarbon dates at fifteen sites as well as re-examining some of the existing radiocarbon-dated sites (seven) in the valley (Doyle 1990). Nineteen new soil-stratigraphic sections are examined in the valley and sampled where appropriate, 15 were radiocarbon dated. The sites from Doyle (1990) are annotated as “P#” while those in the current study are annotated as “C#” so as to separate the two data sets.

Samples were returned to Australia and analysed by X-ray diffraction, X-ray fluorescence, soil chemical analysis, reflecting light microscope, and scanning electron microscope examination. This analysis is used to aid in the determination of the provenance and characteristics of the materials. A 1:20,000 topographic map used in earlier studies was digitised to form a DEM while detailed 1:5,000 topographic maps have been used to provide new insight into landscape processes as the sites under consideration. The work is not a pedological study or soil survey, and thus only abbreviated soil profile characteristics will be provided, sufficient for stratigraphic interpretation. Detailed soil mapping and soil descriptions are provide in Doyle (1990). One aim of the current study is to determine in more detail the soil-stratigraphic history. Indeed many of the soil materials are not in situ but are transported soil colluvia or fragments of former soils entrained within debris flows. Thus they do not represent soil profiles formed in situ.

Overview of study area
The Leipsokouki valley is steep, narrow and deeply incised (Figures 1.3 and 1.4). The elevation ranges from approximately 500 m in the lower valley to nearly 1000 m
on the upper catchment divide. The geographic location of the study area in north-central Greece is shown in Figures 1.1 and 1.2. It is incised into weakly consolidated Tertiary sedimentary rocks, dominantly mudstones and fine sandstones, and Plio-Pleistocene gravels (see Chapter 4). Cover beds of silty texture occur on the upper slopes and dividing ridge. Prior to human or climatic disturbance the catchment would have been in a quasi-stable equilibrium with stream power capable of removing the largely fine-grained sediment generated within the catchment. With in the valley there is evidence of well-developed soils with strongly structured B2 horizons and precipitated pedogenic calcium carbonate nodules in growth position. These soils are preserved on remnant ground surfaces on the valley divide.

The alluvial soils do not exhibit such strong pedogenic features. An alluvial valley fill traced the length of the valley was named the Syndendron alluvium by Doyle (1990). Comprehensive dating of this deposit has been one of the key objectives of the present study. So has determining the source sediment for the Syndendron alluvium. During the late Glacial and early Holocene major vegetation changes occurred as steppe gave way to oak woodland. The study also had the objective of determining the impact of climate change, vegetation change, and human activities on the soil formation and landscape processes in the valley.

Debris flow deposits were also noted by Doyle (1990) in the upper catchment along with deep fills of reddish brown soil. In this study dating these deposits has helped determine the timing and likely processes that led to their occurrence.

Mid to late Holocene alluvial fills occur in valley floor and these have been further dated in an attempt to determine the factors leading to their initiation and aggradation. The role of fire in landscape processes can be catastrophic, and this study had the aim of examining the role of fire throughout time in the valley. Artefacts from the Upper Palaeolithic found in the catchment and are associated with pyrotechnic features.

The role of humans and landscape processes has been investigated by comparison of all archaeological data in the region to the dated soil and sedimentary deposits in the valley.
Figure 1.1 Locality map showing the Nomos of Grevena in northern Greece and the Haliakmon River which drains the region in the gulf at Thessaloniki (Doyle 1990).
Figure 1.2 Location map showing the study area within the Nomos of Grevena. The key rivers and the mountain ranges are also shown, refer to figure 1.1 for location of this map within northern mainland Greece (after Doyle 1990).
Soils of the local area

Doyle (1990) defined a broad elevated plain in the central Nomos of Grevena and named it the Mersina surface. The surface extends over approximately 200 square kilometres and has an elevation of 610-630 m. It has a flat to gently undulating topography and occurs in the lower part of the Leipsokouki catchment. The soils on the surface are dominated by deep dark reactive clay soils classified as Vertisols and Mollisols (Soil Survey Staff 1992). The Mersina surface is underlain by a sequence of alluvial sediments and calcareous paleosols inter-bedded with imbricated, rounded gravel and stones layers of alluvial origin, loess beds and paleosols.

The soils in Grevena mostly are moderately deep and fertile (Spiropoulou et al. 1983a; Spiropoulou et al. 1983b; Oikonomou et al. 1985; Spiropoulou et al. 1985; Oikonomou et al. 1988; Doyle 1990). This is a result of clayey, base-rich parent materials and low rainfall, meaning low level of leaching. This is particularly true in the central part of the Nomos of Grevena on the extensive, deeply incised, Pleistocene plain called the Mersina surface (Doyle 1990). On this elevated plain deep calcic soils have developed in a stable environment with low rates of erosion. Bordering this incised central plain are foot hills of Tertiary marine sediment. These foothills rise up to meet the Pindos and Vourinos Mountains, which are formed from ophiolite complexes and associated limestone, flysch and melange sediments (Figure 4.1). The Leipsokouki valley extends from the incised central plain to these foothills (see Figures 1.2 and 1.3).

The modern cropping and grazing system appears to be increasing soil loss due cultivation up and down the slopes, instead of along the contour. Erosion is also aided by the clearing of brush for new fields and displacement of the grazing animals on to the marquis-covered steeper terrain (Plate 1.1). Appropriate control measures for soil erosion appear to be largely ignored by current agricultural practitioners. This may be partly due to the moderately thick silty clay loam topsoils which have high cation exchange and base saturation (Spiropoulou et al. 1983a; Oikonomou et al. 1988; Doyle 1990). As a consequence of high nutrient retention throughout, these soils suffer lower levels of production loss following topsoil erosion than soils that are dependent on thin topsoils for nutrient supply (Olsen 1984). Thus erosion commonly
Figure 1.3 Topographic map of the Leipsokouki Catchment based on 1:20,000 contour map with 20 m contour intervals. Location of stratigraphic sections with symbol C# and blue dot. Note also the soil profiles from Doyle (1990) marked as P# and stratigraphic sections as S# (both as red triangles).
Figure 1.4 Terrain model of the Leipsokouki Catchment based on 1:20,000 contour map with 20 m contour intervals. Blue dots indicate locations of sites (this study) and red triangles indicate soil profiles from Doyle (1990).
Figure 1.5 SPOT satellite image of the Leipsokouki catchment from 1995. Note extensive areas of greyish land (bare soil/rock) in the mid catchment area. Bright pinkish areas indicate irrigated land while the dull pink signifies dry land agriculture. Note the town of Grevena is also greyish due to the road and buildings which are similar to bare ground or rock while the villages are a mixture of brighter pink due to the vegetable gardens and irrigated fields near the village.
continues until the entire topsoil is lost. However, if this erosion is not controlled eventually the whole soil maybe lost, leaving exposed only the bedrock, with large implications for production and versatility of the land. This has happened in some fields in the Leipsokouki catchment, and farmers are now ploughing up the weathered bedrock (Doyle 1990).

The central part of the Leipsokouki catchment is an area where erosion is very extensive. The burial of well-developed and truncated soils is common, indicating erosion and transport of soil and rock colluvium during the Holocene. The presence of deep gullies is a further indication of past and present landscape instability. Determining the causes and timing of this process is one of the aims of the present study. Certainly in the modern environment degradation of the vegetative cover and intensive grazing is preventing stabilisation of the majority of large gullies in the landscape. Goats are notorious for their voracious appetite and agility in climbing steep slopes to reach food (Reifenberg 1959; Olsen 1984). The combination of fine textured unconsolidated alluvium and weakly consolidated to moderately consolidated bedrock units means that this area is naturally susceptible to erosion and stream incision. The denudation of slopes and also soil compaction by sheep and goats enhances run-off, modifying the drainage pattern (Doyle 1990). Both these factors increase gully erosion. Also on many slopes soil creep and other forms of mass movement have occurred during the Holocene.

Today very little effort is placed on preventing the migration of gullies into the valley sides. There appear to be no limitations on grazing of gully walls, and sheep and goats are able to maintain their denuded state. Networks of compacted tracks formed by sheep and goats cover most slopes in the valley.

In summary, the soils of the Leipsokouki catchment and the central lowland Nomos were dominantly quite thick fertile soils, such as mollisols and vertisols with some inceptisols and alfisols on slopes (Soil Survey Staff 1992). These soils appear to have supported moderate human populations throughout most of the Holocene and late-glacial periods (Wilkie and Savina 1992; Wilkie 1995). However, the hill soils and landforms of the Leipsokouki valley have become eroded during the late-glacial and
Holocene periods. Determining the timing and causes of this degradation is part of the current study.

Leake (1804 AD) (as cited in Moody and Rackham 1988) indicated the agricultural capability of the fertile Mersina surface soils nearly 200 years ago when he said “the country [around Grevena] resembles Northern Europe more than Epirus or the other parts of Greece, consisting of an undulating surface, well supplied with sources of water, intersected by numerous stream and diversified with beautiful groves of oak and other timber trees. Nor is the soil inferior to the aspect, but would produce corn in great abundance, if population and security were here in any moderate proportion to natural advantages. The many loaded horses and mules, which we met on the road from Metzovo, and the far greater part of which were charge with flour show that even now it supplies Epirus and the islands with bread.” Leake must have been referring to springs for water supply as most streams are deeply incised into the Mersina surface. Also the water and nutrient demands of corn are probably the key reasons that the cereals wheat and barley are grown both now and 200 years back.

Vegetation and land use
The present abundance of oaks in some parts of the lowland central Nomos of Grevena suggests that there was once a mosaic of deciduous oak woods and steppe throughout the area (Greig and Turner 1974; Moody and Rackham 1988). Since man's appearance in the Upper Palaeolithic this ancient vegetation cover has been heavily modified, particularly since the Bronze Age. Greig and Turner's (1974) pollen diagram for the old lake of Philippi near Thessalonica covers the Neolithic and Early Bronze Age. It suggests mixed oak forest with oak on heavier soils in the Neolithic, changing to increased marquis vegetation in the Bronze Age at that site.

Over half of the area of the Nomos of Grevena is dominated by woodland, with grassland and cultivated areas in the remainder (Chester 1991). Tree clearance by people for firewood, fodder, construction and cultivation, and the effects of overgrazing on hill slopes have reduced the natural vegetation of the Leipsokouki catchment (Plate 1.1). Present human activities have a strong influence on the vegetation pattern and land use in the Leipsokouki catchment. Modern agriculture involving clearing areas for cultivation of cereals, grazing of goats and sheep on hill slopes, burning of stubble and tree felling have
combined to reduce the original natural mosaic of oak wood and steppe to a minimum (see Plate 1.2). The vegetative cover in the Leipsokouki catchment can be grouped into five general vegetation-land use classes, discussed in the following sections (Moody and Rackham 1988; Doyle 1990).

Oak wood and forest
Today the oak woodland of lowland Grevena is comprised of deciduous, semi-evergreen, and evergreen oaks (Chester 1991). The evergreen oaks occur on the warmest sites, largely southeast Grevena, and deciduous oaks on the colder sites, while the semi-evergreen species are in intermediate locations (Chester 1991). Moody and Rackham (1988) have distinguished at least seven oaks occurring in the Nomos of Grevena: *Quercus trojana*, *Q. cerris*, *Q. brachyphylla*, *Q. pubescens*, *Q. frainetto* and *Q. virgiliana*, but they state that most appear to hybridize, forming a continuum with only *Q. trojana* standing out as a clearly defined species. The prickly-oak, *Quercus coccifera*, which is a typical Mediterranean species, is absent from Grevena, supporting the notion of a sub-Mediterranean climate (Moody and Rackham 1988). Moody and Rackham conclude that Grevena has a distinct environment that is more like central Europe than the rest of Greece. Blocks of oak wood are scattered throughout the catchment, mainly on the steeper slopes (see Plate 1.2). Forested areas cover approximately 5-10% of the catchment area (Doyle 1990). These forests contain closely spaced youthful or mature oak trees that are either managed forest blocks or areas of oak-pasture (see below) that have been protected from grazing long enough to allow the seedlings to grow above grazing height.

Marquis
Large areas of scrubland or marquis (approx 25% of catchment), which are a mixture of oak (dominated by *Quercus brachyphylla*) and juniper (*Juniperus oxycedrus*), occur on hill slopes. This type of vegetation is referred to as "oak-pasture" by Moody and Rackham (1988) and is maintained by the continual grazing of small stock (sheep and goats). Oak is commonly the dominant shrub, but the ratio varies with juniper being dominant on re-vegetating eroded slopes. On actively eroding gully slopes, where there is no soil, a sparse vegetation of cortinus (*Cortinus coggygria*) associated with the grass *Scabiosus staehelina* and minor juniper and oak occurs. Small sycamore and ash trees were also noted in the scrubland.
The marquis vegetation occurs as clumps or patches of shrubs encircled by networks of animal tracks (sheep and goats) indicating heavy browsing. Generally the vegetation is less than 1 - 2 m tall with scattered young oak trees (4-5 m high) that have managed to grow above grazing height. The density of vegetation within the marquis is controlled by the grazing pressure and erosion rate. Higher levels of erosion and grazing seem to correspond with sparser vegetation, greater numbers of animal tracks, and larger areas of bare soil or rock-slope debris.

**Cultivated areas**

Dry-land agriculture prevails in the valley due to a lack of surface water. Wheat and barley are major cash crops grown today throughout the catchment (Plate 1.2). Most gently sloping land amenable to mechanised agriculture is currently in cultivation. Approximately 50-60% of the catchment area is cultivated (Doyle 1990). Although wheat and barley dominate, limited crop rotation to alfalfa and sunflower occurs. Tobacco and corn are grown on a small scale but are limited by moisture deficits. Cultivation involves once-a-year ploughing in autumn when the soils are moist and soft, followed by seeding (Aschenbrenner 1988). The seeds remain in the soil over the winter and germinate when the warmth of spring arrives. The harvest is in July-August. Between July and late September-early October stubble covers the fields that are then burnt before ploughing (Plate 1.2). The soils are therefore fallow and susceptible to erosion during the autumn and winter periods. It is at these times that the greatest and most intense rainfalls occur (refer Figure 1.6).

**Grassland - pasture**

Small areas of wild mixed grasses, dominated by the perennials *Festuca* and *Poa timoleontis* (Moody and Rackham 1988), occur on the lower terraces in the valley floor, where recent soils occur (entisols and inceptisols). Grassland also occurs on uncultivated steeper slopes and isolated recently abandoned small fields where woody vegetation has not yet re-established. In places where soil moisture retention and aeration is greater the grassland includes bracken (*Pteridium aquilinum*). Grassland cover is particularly common on the valley slopes in the lower catchment where well-drained gravely soils occur. Approximately 10% of the catchment is grassland (Doyle 1990).
Figure 1.6 Vegetation of the central Mediterranean (from Macklin et al. 1995 after Eyre 1968).
Un-vegetated areas
Many areas of bare rock and barren slope debris occur on hill slopes and in gullies and stream beds. These bare areas are an indication of sheet and rill erosion. Unvegetated areas cover approximately 10% of the catchment area (Doyle 1990).

Climate of Grevena
The climate of lowland Grevena is intermediate between Mediterranean and Continental, described as “sub-Mediterranean” by Moody and Rackham (1988). This is because it is located within an inland basin 140 km from the coast and is in the northern part of Greece. Summers are hot and dry (typical of Greece) but the winters are cold with heavy rain, snowfalls, and frosts more typical of central Europe. Rainfall maxima occur in autumn and spring (Figure 1.6). The result of the cold winter and dry summers is that most plant growth occurs in spring, early summer and autumn (Moody and Rackham 1988). The following summary of climate is based on three main sources of information: climatic data collected at Grevena over the period 1978 to 1987, data from Biel (1944) and calculations using the methods of Thornthwaite and Mather (1957).

Winds
The weather patterns of the Balkans are dominated by northwest moving air masses. The surface winds have extremely variable in direction and are strongly influenced by topography. The winter winds are west and northwest, spring winds between west-southwest and west-northwest, summer winds west and north, and autumn winds north-northwest (Biel 1944).

Temperature
The mean annual temperature for Grevena is 12.7° C. The mean winter temperature is 3.9° C, with January the coldest month at 3.2° C. The mean summer temperature is 21.6° C, July being the warmest month at 22.7° C (refer Figure 1.6). Winters are cold, with an estimated 40 days of ground frost annually. This estimate is based on comparison of mean monthly temperatures for the year and for the winter months with comparable climate stations in the Balkan Peninsula, Sinj (Yugoslavia) and Larissa (Greece).
Figure 1.7  a) Potential evaporation vs rainfall as calculated after Thornthwaite and Mather (1957) for Grevena climate station (550 m asl.). B) Monthly rainfall and air temperatures for Grevena plotted using a ratio of 2:1 after Spiropoulou 1983. Figures and data from Doyle (1990).
Precipitation
Grevena lies in the rain shadow of the Pindos Mountains and receives 643 mm of rainfall annually, while Corfu, 110 km to the west of the Pindos Mountains receives 1217 mm/year. Maximum rainfall occurs in autumn and spring, with mean monthly autumn rainfall of 75 mm and 63 mm respectively. November is the wettest month with 108 mm average rainfall. Minimum rainfall occurs in summer with mean monthly rainfall of 25 mm and with July the driest month (22 mm). Winter rainfall is moderate, with mean monthly rainfall of 53 mm (see Figure 1.6). In the Balkan peninsula the most intense rainstorms occur in late spring - early summer and in late autumn (Biel, 1944). The total number of days on which snowfall occurs is estimated at 10-15 by comparison with Sinj (Yugoslavia) and Skopje (Yugoslavia) that have 11.7 and 13.3 days of snowfall respectively (Biel, 1944).

Soil moisture and temperature
The soil moisture regime is xeric (i.e., dry in summer), typical of Mediterranean climates, except that the maximum rainfall occurs not in winter but rather in spring and autumn. The soil temperature regime is on the boundary between thermic and mesic, and, depending on which conversion formula is used, can be classified as either (Doyle 1990).

Soil moisture surplus can be expected from late autumn until late spring. The calculated net moisture surplus is only 25 mm annually above estimated evaporation (Thornthwaite and Mather 1957). The rainfall and temperature relationships indicate soil leaching will mainly occur in autumn and winter, when high rainfall coincides with low evaporation. Little or no leaching occurs in the warm dry summers, allowing basic soil cations to accumulate in the profiles (Doyle 1990).

Moody and Rackham (1988) report complaints that the climate is getting drier in Grevena and that maize has grown less tall in the last 10-15 years and that springs are drying up.
Plate 1.1 Grazing of mixed herds of sheep and goats is an important land use in the region on steeper, commonly eroded lands (A). Cutting of tree for supplementary fodder a common practice (B). Natural springs are critical for stock (sheep, goats and donkeys) watering in the dry summer period.
Plate 1.2 Wheat and barley are important dry land crops in the region and burning of stubble is a common land management practise to control disease prior to cultivation and planting. Cereals are planted in autumn and harvested in late spring. Woodlots of oak occur on some of the less eroded steeper sites. Lower photo shows slumping which provide exposure for site P37 (see Chapter 5).
CHAPTER 2 Literature Review

Introduction
This literature review covers the issues of the population and level of agricultural development in the Grevena region and broader Macedonia as well as neighbouring Epirus. It is important to examine this material in an effort to understand what types of impact man may have had on the landscape of Grevena. The second part of the literature review deals with the written history of man’s interaction with the landscape; this comes mainly from central and southern Greece but also other parts of the Mediterranean basin. The third part is a review of published soil stratigraphic studies that shed light on the impacts of climate and man in the landscape in other parts of Greece and the Mediterranean. The fourth section examines the use of soil stratigraphy and sedimentary sections for interpreting the past landscape processes. The later sections examine the role of pollen analysis and other paleo-climatic techniques in providing a history of both the climate and vegetation record. The review concludes with an examination of the role of tectonics.

The archaeological record of the region

Introduction
This review utilises information from the literature and data on the archaeological record from Grevena (Wilkie and Savina 1992). A surface archaeological survey was conducted in the region during the summers of 1987, 1988 and 1989. Farmers’ fields, road cuts and stream bank exposures were surveyed across the region. Fields were surveyed with 4-5 persons walking in a straight-line formation across the area with all artefacts collected, classified and catalogued (Wilkie and Savina 1992). The extensive erosion in the catchment and the wider region ensured a wide variety of sites were exposed. In the Leipsokouki catchment all road and stream exposures were examined for archaeological artefacts. In addition six transects were run from the ridge tops to the valley floor with teams of 10-15 American archaeology students undertaking visual surface survey. This surface survey was undertaken to ensure all parts of the catchment were checked for artefact distribution.

The archaeological record in Grevena begins in the Palaeolithic. Wardle (1988) mentions two Palaeolithic sites in Macedonia and several in neighbouring Epirus.
Recently Bailey *et al* (1997; 1999) provided much information on the upper Palaeolithic from Epirus. Wilkie (1992) lists five Palaeolithic sites in the Nomos of Grevena. The presence of these sites so close to Grevena indicates man has interacted with the local environment for at least 15,000 years. Early Neolithic communities flourished in Grevena while the middle and late Neolithic are well represented in neighbouring providences. The early Bronze Age until *ca.* 2000 BC is also well represented (Davidson 1980; Wardle and Sakellariou 1988; Wilkie 1993). During the middle Bronze Age the Minoan civilisation developed and is best known for the palace site of Knossos on Crete and pumice-buried ruins at Akrotiri on Santorini (Thera). The destruction of Minoan Crete in *ca.* 1470 BC coincides with the eruption of the Santorini volcano and the earthquakes and tsunamis which accompanied the pumice and ash falls (Wright 1968). Following the decline of the Minoans the centre of Greek Civilisation moved to the southern mainland (Davidson 1980). Whether this was due to environmental decline, primarily the loss of soil cover is not known. But Minoan Goddesses that are symbolic of nature and the fertility of the soil start to appear on mainland Greece after 1400 BC (Kitto 1963). Certainly the last Minoan art leads directly into the Mycenaean culture on the mainland (Kitto 1963). The Mycenaean community began around 1600 BC and marks the beginning of the Late Bronze Age, when Mycenae became the political centre of Greece. The Mycenaean empire ended *ca.* 1200-1100 BC and the Dark Ages commenced (Iron Age and Archaic/Geometric periods) (Wright 1968). Grevena is well represented in the Iron Age but little is known about the Archaic and Geometric periods before the record picks up after 750 BC. Expansion and development of warring tribes then led to the establishment of the city-states in the Classical period. The pinnacle of Greek influence occurred in the Hellenistic period, which began with the reign of Phillip II of Macedonia (360 BC) and ended with the conquest by the Romans in 148 BC (Davidson 1980; Hammond and Andronikos 1988). Macedonia became part of the Byzantine Empire when the Roman Empire was divided in AD 395 (Tsitouridou and Browning 1988). Macedonia was included in the 1st Bulgarian Empire in the 800s and Serbian Empire in the 1300s (Ahrweiler *et al.* 1988). From 1389 to 1912 the Turks had possession of Greece during the Ottoman Empire. The Balkan allies defeated Turkey in the 1st Balkan War in 1912 and Greece became self-ruling.
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**Figure 2.1** Archaeological timescale after Wilkie and Savina (1992).
Plate 2.1 Paleolithic stone tool located near the village of Itea, Nomos of Grevena, Greece!

Plate 2.2 Examples of pottery from Grevena. A) Early Neolithic pot sherds from Mega Sirini. B) Arrowhead and geometric pottery from Grevena region.
Upper Palaeolithic (20,000 yr BP - 8300 BC) and Mesolithic (8300-6000BC)

Wilkie and Savina (1992) list five Palaeolithic sites in the Nomos of Grevena. They include a Palaeolithic tool at Mikrokisoura, stone tools at Kolokithaki, two Palaeolithic finds near Polineri, and a stone flake at Lavdas (Plate 2.1). These villages are 9, 14, 15 and 17 kilometres respectively from the study area. Wardle and Sakellariou (1988) discuss evidence of two fine-flaked Palaeolithic stone hand-axes found near Paleokastro in the foothills of the Vourinos Mountains. This village is 18 kilometres from the study area and lies on the border between Grevena and the Nomos of Kozani. This evidence shows that hunter-gatherer clans were active and interacting with the Grevena environment, perhaps as long ago as 40,000 yrs BP. Pope et al (1984) discuss middle Palaeolithic stone tools dated to 24,900 ± 1,100, >39,000 and 37,000 yr BP at Asprochaliko and Kokkinopilos in Epirus, approx 75 km southwest of Grevena township. Galanidou et al. indicate human occupation at Kastritsa, near Ioannia sometime before 23,900 ± 100 yr BP (2000). Other late Upper Palaeolithic sites (17-10 kyr BP) include the rock shelters at Klithi and Boili on the western side of the Pindos Mountains only 30 km from the study area (Bailey et al. 1999; Woodward and Goldberg 2001; Woodward et al. 2001). These shelters contained stone tools (blades and end scrapers) associated with hunting of ibex, chamois and red deer. Another Palaeolithic site occurs in east Macedonia on the Chalkidike peninsula, where a fossilised human skull (Neanderthal?) was found with animal bones in association with chipped stone tools in the Petralona cave (Wardle and Sakellariou 1988). There are also large Palaeolithic deposits in Thessaly (Hammond 1972).

This evidence of Palaeolithic man’s presence both within the Nomos of Grevena and in neighbouring provinces allows for the possibility of human-induced firing and limited clearing of the landscape as early as 40,000 years ago. To what extent these hunting and gathering people disturbed the landscape is not known. However, excavations at Franchthi cave on the Peloponnesus indicate Palaeolithic people were hunting wild horses and had tools of flint and chert (Jacobsen 1976). Later, as the glacial conditions abated the diet switched to red deer and bison with some wild goat. Plants eaten included wild pulses such as vetch and lentil. Land snails and marine molluscs were also eaten. Tools of flint and chert became more numerous in the
Upper Palaeolithic around 12,000 – 10,000 years ago (Jacobsen 1976). The Mesolithic strata (8300 BC – 6000 BC) at Franchthi cave show that wild horses and goats were no longer hunted and that red deer was the dominant meat. This change may reflect the moistening climate and a landscape change from grassland steppe to open forest (Jacobsen 1976). Plant foods now include wild pulses (peas), pistachios and almonds. These foods were supplemented by land and marine molluscs and increased amounts of fish, especially in the later Mesolithic (after 7250 BC). Obsidian tools also appear after 7250 BC that indicate trading with the Greek island of Melos (Jacobsen 1976).

Runnells (1995a) indicates that research in Greece on the Palaeolithic and Mesolithic periods has been neglected due to the Bronze Age and Classical periods taking the focus. He summarises the Palaeolithic sites in Greece and confirms the renaissance in this area of research. Runnells (1995a) indicates there are 11 -13 Mesolithic sites found in Greece, five of which occur in neighbouring Epirus. While no Mesolithic sites have been identified in Grevena it seems this may only be a matter of time as sites occur in the neighbouring regions of Thessaly and Epirus.

Neolithic (6000BC – 3000BC)
Evidence from southern Greece at the Franchthi cave site in the Peloponnesus suggests the Early Neolithic was a time of change away from wild foods to farming of wheat and barley as well as the domestication of sheep and goats (Jacobsen 1976). As tools became more sophisticated, with axes of hard stone on wooden or antler handles, land clearing would have been possible. Coarse millstones and flint blades used as sickles support the idea that agriculture had arrived in Greece (Jacobsen 1976).

In Macedonia, at the site near Neo Nikomedeia, the Neolithic included settlements and mixed-substance economy in which sheep, goats and small numbers of cattle and pigs were raised (Rodden 1965; Wardle and Sakellariou 1988). The Neolithic people also cultivated primitive wheat (einkorn and emmer) and various types of barley and the legumes vetch, peas and lentils (Rodden 1965; Wardle and Sakellariou 1988). In west Macedonia and Thessaly there is evidence of cultivation of wheat, barley and oats dating back to the Neolithic (Renfrew 1973; Hansen 1988). They also hunted
fowl, deer, hare and wild pigs, collected shellfish (mussels and cockles) and caught fish (Rodden 1965).

The Early Neolithic (EN) was a key period of human occupation in Grevena, see Plate 2.2 (Wilkie 1993; Wilkie 1995; Wilkie and Savina 1997). Only a few pot-sherds from Middle and Late Neolithic periods have been recognised in the Grevena region. Seventeen EN occupation sites have been identified, with most situated on broad terraces adjacent to the Haliakmon and Venitikos Rivers (Wilkie and Savina 1992). Wilkie (1995) believes that when the Early Neolithic settlers arrived they would have found a landscape dominated by oak woodland and some limited tree clearance. Wilkie (1995) believes this is supported at Knidi by archaeological evidence of wooden beams and planks used in house construction. Overall, (Wilkie 1995) suggests the impact on the landscape of EN settlers was probably minimal. The low number of sites, the small size of the occupation sites and the abandonment of the region in the middle and late Neolithic seem to support this conclusion. However use of fire, cultivation and grazing pressure could have placed pressure on the vegetative cover of the landscape. Fire may have been an important method of land clearing or for hunting and attracting game as in Australia and Papua New Guinea (Hayden 1979; Flannery 1994).

Wilkie and Savina (1997) note that one of the striking features of the Neolithic in Grevena is the high number of sites in the Early Neolithic and the rarity of middle and late Neolithic occupations. In summary, grazing, weaving and agricultural activity appear to have begun in Grevena in the early Neolithic ca. 7500 – 6500 years BP.

Neolithic artefacts found in the Macedonian region include knife and sickle blades of chipped quartz or chert, polished axes in a range of hard lithologies, and tools of bone, including awls, needles, burnishers and spatulas (Rodden 1965; Wardle and Sakellariou 1988). There is also evidence for the craft of weaving from both impressions on clay artefacts and presence of conical spindle whorls, which indicate the importance of grazing industries in the broader region. At Nea Nikomedea 90 km northeast of Grevena quite substantial houses (7m wide) were constructed using large wooden beams, indicating the use of local tree resources. In the Middle Neolithic at a site in Servia (35 km east of Grevena) houses with large central wooden post and
split-planked floors again indicate the local use of wood resources in the Neolithic period. Timbers used include chestnut, oak, pine and cedar (Hammond 1972). Thus we have the basic components of an established agricultural economy in the Neolithic in Macedonia. The sites at Knidi, Servia and Nea Nikomedeia indicate tree clearance was apart of this Neolithic economy.

**Bronze Age (3000BC – 1100BC)**

The change from the Neolithic to early Bronze Age in Macedonia is poorly understood (Wardle and Sakellariou 1988). In the early and middle Bronze Age Macedonia appears to have been a cultural backwater (Wardle and Sakellariou 1988), perhaps due to the fact much of the region is poorly suited to olive growth (Macklin *et al.* 1995). The middle Bronze Age is probably the most poorly represented in Macedonian prehistory. In the Mycenaean period (late Bronze Age) subsistence was based on mixed farming of millet on the Macedonian plain and vines, as grape pips appear in archaeological sites (Wardle and Sakellariou 1988).

Late Bronze Age (Mycenaean) swords and a spearhead have been found near Grevena (Wardle and Sakellariou 1988). At Servia 35 km east of Grevena homesteads were defended with ditches and constructed of timber-framing. They contained pottery showing links to both Thessaly and central Macedonia (Wardle and Sakellariou 1988). Pottery of the so-called “baking-plate” type, with low rims, spouts, and thin, slightly concave bases have been linked with processing milk for cheese and yoghurt production during the Bronze Age at Servia. Loom weights and spindle whorls indicate that spinning and weaving were important crafts. Flint and chert blades and polished axes were used for wood cutting, while chert blades show wear consistent with sickle use (Wardle and Sakellariou 1988). These data suggests a well-developed Late Bronze Age agriculture throughout Macedonia.

In Grevena it is not until the Late Bronze age that the population reached what it was in the Early Neolithic (Wilkie 1995). Nineteen sites from the Late Bronze Age have been identified, and nearly all are on steep slopes. Most of the archaeological material has been collected from colluvial fills generated by hill slope erosion (Wilkie 1995). None of the sites is definitely *in situ*. The fact that a third of the sites lie above 900m indicates some form of pastoral transhumance agriculture was practised.
The sites are not near the main rivers but seem to be linked by elevation – a highlands phenomena (Wilkie 1995). Eighteen of the sites are near significant springs. Seventeen of the sites face east. The sites are often located close to one another. Transhumance and village pastoralism are indicated by the presence of large springs, highland locations and warm aspects. During summer the high pastures would have provided good feed, while in the winter migration to lower levels, probably Thessaly, would have provided winter pasture and oak woods for fodder and better agricultural lands (Wilkie 1995). This evidence has important implications for interpretation of the possible impacts of humans on any erosion-deposition dated to this period, as overgrazing of steep slopes may readily lead to denudation and an increase in soil erosion.

In neighbouring Epirus tall oaks and white poplar were famous from the time of Homer (Hammond 1967) and were a very important part of the economy.

Wright (1968) indicates the fall of the Mycenaean civilization about 1200-1100 BC which led to the Greek Dark Ages.

**Iron Age (1100BC – 750BC)**

Population change from the Late Bronze Age is hard to establish in Macedonia. Iron Age artefacts and designs indicate links to the whole of southeastern Europe and southern Greece (Wardle and Sakellariou 1988). However, these links appear no stronger than those developed in the Bronze Age, and Wardle and Sakellariou (1988) doubt a barbarian invasion from the north.

In Grevena twenty-seven villages had sites with Iron Age sherds and a further fourteen had probable Iron Age sherds. This was clearly a very important period with a moderate population in Grevena. In the study area (Leipsokouki valley) more intensive survey work was undertaken and up to five Iron Age sites have been identified at Syndendron, and three were identified at Mega Sirini (Wilkie and Savina 1992). Thus the way in which these moderate Iron Age populations used the landscape may have had large impacts on soil and sediment movement within the valley.
The Pindos Mountains of Grevena are one of the areas the original Macedonians are thought to have come from. Iron Age tombs at Vergina, where the Haliakmon enters the Macedonian plain, indicate the increasing sophistication of the Iron Age people. The Pindos and Vorinos mountains would have provided suitable summer pastures for both sheep and goats, while the Macedonia plain provided good arable lands and winter pastures. It was at this important geomorphologic gateway that the Macedonian empire arose.

In neighbouring Epirus bronze artefacts representing horses, ducks and goats appear in the period 1100-750BC. Hesiod (between 1000 and 700 B.C.) describes the plain of Ioannina with many crops and good meadowland, wealthy in flocks and shambling cattle (Hammond 1967; Hesiod ca 700BC).

**Classical Period (750 BC – 360 BC)**

Colonists were attracted to Macedonia in early Classical times by the products of the interior lands (eg Grevena), particularly timber, which passed through lower Macedonia to the Aegean Sea via rivers such as the Haliakmon and the Axios. Large mountain villages in Grevena such as Perivoli and Samarina may have had up to 500 families during summer grazing periods (Hammond and Andronikos 1988). Surplus meat, cheese, wool and hides would have been traded for bronze vessels and pottery (Hammond and Andronikos 1988). From 650 – 500 BC Macedonia was established on the plain at Vergina and extended to Edessa via the Loudias River with an adopted settled agricultural life (Hammond and Andronikos 1988). Transhumance pastoralism is still practised, aiding trade that by the mid 6th century BC had penetrated far inland. The trade was driven by timber for shipbuilding, foodstuffs, animal products and mineral wealth (Hammond and Andronikos 1988).

In the Nomos of Grevena there are 31 Classical sites located near the villages of Dasohori, Deskati, Elatos, Itea, Kali Rachi, Katakali, Kipourio, Kosmati, Mavronoros, Monachiti, Polineri, Prosvoro, Mega Sirini and Syndendron (Wilkie and Savina 1992). The last two villages are in the study area, and they contain eight Classical sites. The Classical sites have a distribution similar to that of Hellenistic sites (Wilkie and Savina 1992). The Classical sites indicate that settlements existed in Grevena before the arrival of Philip of Macedonia. In fact there is good evidence of large
settlements dating from the Iron Age in Grevena (Wilkie and Savina 1992). This suggests Grevena was not simply a land of nomadic shepherds at these times. Evidence from the villages of Tsiani, Prosvoro and Polineri show fortifications commenced during Classical times. The pottery appears to be largely locally made and indicates a degree of self-sufficiency (Wilkie and Savina 1992). The rich assortment of pottery also suggests the standard of living was well above the primitive level indicated by Hammond and Andronikos (1988). They also state that “between 460 and 360 BC the standard of life in Upper Macedonia was at a primitive level and the area was remote from the orbit of Greek trade”. However, some pottery from Dheskati (southern Nomos) appears imported and thus indicates that some trade with Thessaly was occurring in Classical times (Wilkie and Savina 1992).

Hammond (1967) reports that neighbouring Epirus at 385 BC lost 15,000 men in the battle with the Illyrians, suggesting a sizeable local population.

Greek expansion after 750BC was driven by the need for farming lands and not trade or “factories” producing industrial products (Kitto 1963). The Greek farmer lived a precarious existence, and the call for land redistribution was often heard in Greece. Colonisation was always a good safety valve (Kitto 1963). Poor peasant farmers with a large land mortgage have a strong drive to migrate to new lands for potential wealth and freedom. New lands could also provide new crops and products and inevitably trade in many items of both agriculture and industry (Kitto 1963).

After 500 BC in Macedonia the population growth was driven by increasing trade with Asia Minor and Egypt as Balkan silver was prized for its purity, while military and naval forces needed timber, foodstuffs and clothing materials (wool, hides). This pressure impacted on the environment, as the town of Strepsa, which was on the coast near the mouth of the Echedoros River in 435-431 BC, is now 13 km from the coast (Hammond and Andronikos 1988).

In summary the Classical period represents eight sites in the study area, indicating this period was as active as in the Iron Age, Late Bronze Age and Early Neolithic. The fortified sites and exotic pottery indicate Grevena was an active trading agricultural
region during the Classical period and not isolated from the rest of Greece (Wilkie et al. 1990; Wilkie and Savina 1992; Wilkie 1993; Wilkie 1995).

**Hellenistic Period (360 BC –148 BC)**

Philip II took Macedonia from a group of highland shepherds to farmers and town dwellers with woven clothes and a law-and-order system (Hammond 1972). Alexander the Great is quoted as saying “Philip found you nomadic and poor, clothed as most of you were in sheep-skins, as you pastured your few sheep on the mountains,… and he gave you cloaks to wear instead of sheep-skins, brought you down from the mountains to live in the plains… made you inhabit cities and civilized you with good laws and customs”(Hammond 1972). On the plains Philip introduced measures to provide flood control, irrigation and land drainage, while new agricultural land was opened up and forest clearance increased (Hammond 1972; Ellis et al. 1988). Philip II saw remarkable population growth. Macedonia underwent immigration during his reign that would offset any slower birth rate due to so many men being absent with the military (Ellis et al. 1988). The total Macedonian population is estimated at 0.5 million at the time of Alexander the Great and this increased by 25% between 334-323 BC, based on military information (Ellis et al. 1988). During Philip’s reign figs, grapes and olives were introduced. While greater security and increasing wealth fuelled population growth, much of this remained in the rural countryside (Ellis et al. 1988).

Most of the Hellenistic sites in Grevena are unfortified settlements in the lowlands, although larger and fortified sites are located in the western foothills (Wilkie et al. 1990; Wilkie and Savina 1992; Wilkie 1993)(see Plate 2.3). Numerous sites occur along the Haliakmon River. The Hellenistic in Grevena reflects the westward expansion of Macedonia. This began when Philip II moved to defend the western part of his territory after 358 BC. Whether the border extended to the Haliakmon River or only to the crest of the Vournios Mountains is not clear. In the Nomos of Grevena over 60 Hellenistic sites have been located indicating it is one of the most populated periods in ancient history (Figures 2.4 and 2.5). The sites are the largest in ancient times some up to 10 hectares. Many roof tiles suggest a local industry requiring wood for firing along with local pottery manufacture that mimics that of Pella (Wilkie and Savina 1992). Also limestone blocks were cut and transported about the region for
construction. Hellenistic loom weights have been found in abundance, and sheep and goat bones found in a colluvial deposit near Syndendron suggest local weaving was well established (Wilkie and Savina 1992). Burnt barley/wheat seeds found near the village of Itea are dated to 2530 ± 130 (Wk1584), indicating cereal agriculture was active.

Most of the fortified sites are found on the western margins of the Nomos of Grevena, at elevations that still suit agriculture and grazing (ca. 1000 m). These sites command views of strategic routes and river fords. They suggest the Pindos Mountains were the margin of the Macedonian empire (Wilkie and Savina 1992).

Aristotle (384-322 BC) remarks on the healthy size of all quadrupeds in neighbouring Epirus and ascribes both their size and high milk yield to fine pastures that are grazed year round (Hammond 1967). While Strabo (63 BC-AD 21) reported the whole of Epirus was well populated before the time of the Roman occupation. Hammond (1967) indicates that the population of Epirus was greater in Hellenistic times than it is today and that the damage to the country through deforestation and erosion is incalculable. He gives the example where 11 ft. of sediment accumulated in the orchestra pit of the magnificent theatre at Dodona, which was capable of holding 20,000 persons (Hammond 1967). Hammond believes the soil erosion and forest clearance affected the groundwater and led to the drying up of hundreds of springs on the mountain slopes.

**Roman Period (148 BC – 3rd Century AD)**

During the Roman period Macedonia was ruled from Rome and attained reasonable stability (Papazoglou and Pandermalis 1988). The Augustan period heralded order and prosperity that lasted almost three centuries. Records of wealthy landlords and wheat exporters indicated the importance of agriculture to the Roman military and to Italy. The Roman governors and their armies generally controlled barbarian invasions from the north. The security of Macedonia depended on governors sent from Rome (Papazoglou and Pandermalis 1988). After 157 BC the prohibition on exploitation of gold and silver mines was lifted and silver coin minting was increased, with local governments reaping part of the benefits.
Plate 2.3 Fortified Hellenistic village in the Pindos mountains foothills, nomos of Grevena (Wilkie and Savina 1992).

Plate 2.4 Late Roman loom weights, iron spear head and pot sherds from the abandoned village of PaleoKnidi (Wilkie and Savina 1992).
The 1st Roman colonies in Macedonia are dated to 43 and 42 BC in the coastal Thermic gulf (Papazoglou and Pandermalis 1988). The Roman road *Via Egnatia*, which linked the Adriatic with the Aegean, greatly influenced economic and cultural development (Papazoglou and Pandermalis 1988). The *Via Egnatia* lay well north of Grevena, reducing the trade implications for Grevena. The arrival of Roman merchants and the establishment of Roman colonies further increased economic and cultural activity. This military road was built to facilitate the control of Roman possessions in Macedonia. The road also acted as an artery of peaceful migration of Italians into Macedonia and for the transportation of goods and administrative control. The immigrants did not establish new towns but colonised and renovated existing Greek towns and cities with temples, public baths and toilets, theatres and market places (Papazoglou and Pandermalis 1988).

Agriculture was supported by a slave culture, with grazing of cattle, sheep and goats, and cultivation for grains and grapes the key enterprises. Also mining, minting, smithing and stone cutting were important industries supported by slaves (Papazoglou and Pandermalis 1988). There were men of great wealth who organised gymnic games and feasts on a massive scale and provided wheat at subsidised prices – but just how large their estates were is not known. Papazoglou (1988) concludes there were imperial agricultural estates in Macedonia in the Roman period.

In Grevena over 140 Roman sites have been identified, indicating that the high population of the Hellenistic probably extended well into the Roman period (Wilkie and Savina 1992). Thus although the *Via Egnatia* did not extend into Grevena the Roman influence is very clearly present in the region. This would suggest the cereal cultivation and grazing prevalent in the Hellenistic times continued in to the Roman period in Grevena. Although Figure 2.5 suggests the population pressure (and land-use intensity?) during the Roman period may have been lower than in the Hellenistic.

In Epirus the size and fine wool of the sheep are mentioned by Varro (116-27 BC), with shepherds tending flocks of 100 animals. Despite Epirus not being famous for cereals the Romans called upon it to provide 20,000 modii of wheat and 10,000 modii of barley in 169 BC (Hammond 1967). This indicates the agricultural demands of the Hellenistic period continued into the Roman era.
Early Byzantine period (late 3rd to 6th century AD)

Early Byzantine period (early 4th- late 6th centuries AD) is seen as a time of low population, as few artefacts have been found from this time (Rosser 1988). Wilkie and Savina (1992) put this down to barbarian invasions that affected northern Greece by Visigoths, Ostrogoths and Huns (Rosser 1988). In the Nomos of Grevena the number of sites drops from over 140 in the Roman period to just over 60 in the early Medieval period (Medieval ranges from 500 - 1450 AD). However, many towns of Roman Macedonia survived almost to the end of the sixth century and played an important part in the later Roman Empire. Following the Goth raids of the second half of the third century, a century of relative peace occurred before regular barbarian raids in the fifth and sixth Centuries (Papazoglou and Pandermalis 1988). The instability of the late Roman period led to lower productivity and economic stagnation before a revival in the fourth century under Constantine the Great. The agriculture of Macedonia at this time still relied on cattle breeding, cereals and vines. Archaeological evidence indicates large villas and estates were part of the agricultural economy. Saltworks, forestry, quarrying (marble) and mining were also important economic activities at this time. The mines were particularly important for providing the raw materials for iron, copper and lead weapons for the defence of Macedonia against barbarian invasions. Marble was exported to all of Greece and to Italy and Syria (Papazoglou and Pandermalis 1988). The road links and the seaports of Macedonia greatly facilitated trade. Other important trades were in leather, dyes, tiles, mosaics and sculpture.

Three Byzantine sites have been identified in the study area at Leipsokouki, Mega Sirini and Mikro Sirini (Wilkie and Savina 1992).

Mid Byzantine (6th – 9th Century AD)

There is only poor and fragmentary evidence of rural life in the middle Byzantine. Avar, Hunic and Slavic invasions were common, with some settlement in varying degrees by new peoples and transplanted populations (Christophilopoulou et al. 1988). Many Macedonian towns were abandoned, and parts of the countryside emptied under the pressure of barbarian raiders. The raiders would burn and pillage and carry off animals, take prisoners and kill men before returning from whence they
came (Christophilopoulou et al. 1988). With Byzantine military attention directed toward the Persians in the east, protection from barbarian raiders from the north and west was often depleted. Depopulation led to increased raiding and forced fragmentation of the Byzantine territory (Christophilopoulou et al. 1988). Successful fortification of Thessalonike prevented a Slavic takeover and provided a stronghold for the Byzantine rulers. Ships unloaded daily at Thessalonike with corn to stock the granaries for any emergency the fortified city faced from the besieging Slavs. Thus the Byzantine authority was largely limited to the coast during this period. Rosser (1988) indicates the Slavs settled in Grevana in great numbers.

From this brief account it would appear that the middle Byzantine period was one of lower population, and this is likely to have resulted in a reduced intensity of land use.

**Late Byzantine (9th Century - 1430 AD)**

Progressive cultural assimilation of the Slavs, largely pastoralists (Rosser 1988), in the Byzantine Macedonia led to a more peaceful and orderly state and power, and prosperity increased, particularly in Thessalonike, the Macedonian capital (refer to Figure 2.2) (Ahrweiler et al. 1988). However, other Byzantine towns in Macedonia such as Veroia, Kastoria and Serrhia became fortified *kastra* (Rosser 1988). In the early tenth century Thessoelonike grew to become the international, political, administrative and military capital of the Western world. With abundant agricultural produce, trade in silk and precious metals Thessalonike underwent intellectual and architectural development (Ahrweiler et al. 1988; Karayannopulos et al. 1988). In the 12th century the *Demetria* a ten-day bazaar attracted merchants and merchandise from Italy, the Black Sea, Phoenicia, Egypt and Spain. The Norman conquest (1185 AD) and later civil dissension of the fourteenth century heralds the progressive decline of Thessalonike and its surrounding areas (Ahrweiler et al. 1988; Karayannopulos et al. 1988). Numerous churches and sherd s from this period occur in Grevena, as shown in Plate 2.5 (Wilkie and Savina 1992).

**Ottoman Period (1430 – 1918 AD)**

Details on settlements in Grevena in the Ottoman period come from church and monastery codexes (ancient manuscripts or historical annals), censuses, and travellers
Plate 2.5 An example of a Byzantine church and frescos at the village of Itea, Grevena.

Plate 2.6 Demonstration of the large demand for timber in ancient building construction. Example from Venice 2001.

NOTE dense timber trussing
accounts of the region (Rosser 1988). The number of post-Byzantine sites (estimate 115) clearly exceeds the number of Byzantine sites (estimate 84).

During the period 1534-1692 the codex mentions 121 settlements in Grevena, while in the 18th century the codex and other sources indicate 126 sites, and the mid-19th century sources indicate 120 settlements (Wilkie and Savina 1992) (cited from Kalinderis 1940, Saratis 1988 and Spanos 1990). The numbers are seen as minimum values because the codex from which most of the data are derived concern only Christians with no mention of sites with entirely Muslim populations (Wilkie and Savina 1992). While the consistence of indicated numbers of settlement is remarkable the key feature of the data is that they indicate a continuity of settlement at 94 villages from the 1534-1692 AD through to the 19th century in Grevena.

**Summary**

Figure 2.1 shows the key archeologically periods for Greece, while the number of sites in each archaeological period are shown in Figures 2.2 and 2.4 (Wilkie et al. 1990; Wilkie and Savina 1992). The number of sites for a given period divided by the length of that period is shown in Figures 2.3 and 2.5. This was undertaken in an attempt to indicate likely population pressure through time. However it is very approximate as no data indicating the population at each particular site is known. The graphs demonstrate the long archaeological record from the Palaeolithic to the present. They also highlight the key periods of human activity as the Early Neolithic, Early and Late Bronze Ages, the Iron Age, the Classical and Hellensitic periods, and the Roman and Ottoman periods. Declines in human activity appear to be the Mesolithic, the middle-late Neolithic, the early-middle Bronze Age, the Archaic and the early-mid Byzantine periods (Wilkie et al. 1990; Wilkie and Savina 1992).

**Evidence of land degradation from the writings of the Ancients**

This section will provide a review of some of the key writings of relevant philosophers in the Mediterranean region to gain a written account of land use, deforestation, population pressures, land degradation, and climatic extremes or changes.
Figure 2.2 Data on the number of archaeological sites from the Nomos of Grevena, after Wilkie and Savina (1992).

Figure 2.3 Data on the ratio of the number of archaeological sites to the duration of the particular period. Data are for the Nomos of Grevena, after Wilkie and Savina (1992).
Figure 2.4 The number of archaeological sites in Grevena (Wilkie and Savina, 1992).

Figure 2.5 The number of archaeological sites in Grevena divided by the duration of the archaeological period. This figure is an attempt to view the intensity of sites during any archaeological period (Wilkie and Savina, 1992).
Deforestation is a critical factor in helping to explain soil erosion. Some of the causes of deforestation described in ancient times include agricultural clearance, pastoralism, commercial tree felling, warfare and charcoal making (Hughes 1983).

**Records of deforestation**

The earliest recording of the exploitative use of forests comes from Oedekoven (1962), who reports organised maritime shipments of timber from Lebanon to Egypt before 3,000 BC. The Phoenicians were also exporting cedar as early as 4,600 BP to both Egypt and Mesopotamia (Mikesell 1969). In Italy in Roman times, Strabo (63 BC-AD 21) complains that the forests of Pisa are being consumed in the construction of buildings in Rome and for villas (Hughes 1983). While Theophrastus, the founder of botany, tells how it was hard to find timber for shipbuilding (Theophrastus 327-287 BC), and later Varro (116-29 BC) indicates the forests are generally limited to the mountains. The destruction of forests is explained by Luceretius (96-55 BC) as “[men] made the woods climb higher up the mountains yielding the lowlands to be tilled and tended” (cited in Hughes 1983). Pastoralism is also seen as a cause of deforestation (Theophrastus 327-287 BC) due to damage that goats cause to the trees and due to the cutting of branches for food. Pliny (AD 62-111), Varro (116-29 BC) and Vergil (70-19 BC) all comment on the degrading effect goats have on plants and young trees. However goats were not the only causes of deforestation; for commercial woodcutting was also important. Several writers describe how logs were felled and removed by draft animals and then floated down rivers and then shipped for sale or use (Strabo 63 BC-AD 21; Vergil 70-19 BC; Pliny AD 62-111). Wood was also used for charcoal making for ceramics and metallurgy (Vergil 70-19 BC; Theophrastus 327-287 BC; Pliny AD 62-111).

Timber supply was strongly related to sea power. Plato indicates the Minoans, power over Athens. “Minos obliged the people of Attica to pay a heavy tribute, because he was very powerful at sea; they possessed no warships . . . nor was their country rich in timber with which they could easily supply themselves with a naval force” (Plato 427-347 BC-a). Statements such as this indicate the strong links between forest utilisation and maintenance of political power.
These written eye-witness accounts remind us of the modern-day forestry debates and struggling Global conservation movement. They indicate a documented culture of tree clearance and forest exploitation extending over at least the last 5000 years in the Mediterranean.

**Ancients comments on the implications of tree clearance**

Vitruvius (90-20 BC) indicates the role of forests for protecting water quality as well as for protecting the land from erosion “water…is to be most sought in mountains…, because in these parts it is found of sweeter quality, more wholesome and abundant. For… in these are many forests trees;… nor do the sun’s rays reach the earth directly and cause the moisture to evaporate…because of the dense forests, snow stands there longer under the shadow of the trees… then melts and percolates through the interstices of the earth and so reaches to the lowest spurs of the mountains, from which the product of the springs flows and bursts forth” (cited from Hughes 1983). Plato was also aware of how soil degradation impacts on water quality and quantity, “moreover it (the soil) was enriched by the yearly rains from Zeus, which were not lost to it, as now, by flowing from the bare land into the sea; but the soil it was deep, and therein it received the water, storing it up in the retentive loamy soil; and by drawing off into hollows from the heights the water that was there absorbed, it provided all the various districts with abundant supplies of spring water and streams, whereof the shrines which still remain even now, at the spot where the fountains formerly existed, are signs which testify that our present description of the land is true” (Plato 427-347 BC-b).

However when the forests are removed the results can be disastrous as Pliny (AD 62-111) warns us; “often indeed devastating torrents unite when from the hills has been cut away the woods that used to hold the rains and absorb them” (cited from Hughes 1983). Certainly modern hydrological models indicate that run-off or catchment water yield is greater under pasture than forests at all stages of plantation growth (Keenan et al. 2004). One of the key impacts of catchment forest cover is a reduction in the magnitude or peak flows on the flood hydrograph.

Not only were water quality and land degraded through forest removal but there was a feeling the loss of forests also affected the weather, which is described as becoming
drier and warmer (Theophrastus 327-287 BC). Commonly forests were cleared for agriculture with the type of trees suggesting which crops would do well following deforestation (Theophrastus 327-287 BC). Similar land classifications were used during the white settlement of lands in Australia (O’Connor et al. 1838; Temple-Smith and Doyle 1996). Ancient writers also noticed that the new agricultural lands performed well for a few years following tree clearing but that this productivity declined over time. Collumella (ca 60 AD) attributed this decline to a gradual exhaustion of the forest humus layer. Similar concerns have been expressed with respect to modern forest-harvesting practices and second-rotation soil fertility (Tasmanian Forest Practises Board 2003). However, Collumella (ca 60 AD) had a remedy for the depleted forest-cleared soils as he says “we may reap greater harvest if the earth is quickened again by frequent, timely and moderate manuring”.

Other authors comment on man’s impact on the environment. Homer, who wrote about the activities of Mycenaeans (ca. 1200BC) in the Iliad and Odyssey (Homer ca 850 BC), describes the impact of water erosion thus; "On many a hillside do the torrents furrow deeply, and down to the dark sea they rush headlong from the mountains with a mighty roar, and the tilled fields of men are wasted." Here Homer comments on active soil erosion that appears to be via rilling and gully ing. The effect is not just the formation of gullies and losses of soil but also the resultant degraded soils now described as incapable of arable agricultural use i.e., “wasted”.

Further comments on Mycenaean times comes from writings attributed to Eratosthenes (276-194 BC) reported by the geographer Strabo (63 BC-AD 21) “in fertility Cyprus is not inferior to any one of the islands, for it produces both good wine and good oil, and also a sufficient supply of grain for its own use. And at Tamassus there are abundant mines of copper, in which is found chalcanthite (copper sulphate) and also the rust of copper, which latter is useful for its medicinal properties. Eratosthenes indicates that in ancient times (Mycenaean 1600-1200BC) the plains were thickly overgrown with forests, and therefore covered with woods and not cultivated; that the mines helped a little against this, since the people would cut down the trees to burn the copper and the silver, and that the building of the fleets further helped, since the sea was now being navigated safely, that is, with naval forces, but that because they could not thus prevail over the growth of timber, they
permitted anyone who wished, or was able, to cut out the timber and to keep the land thus cleared as his own property and exempt from taxes”. Here we find reference to fertile, productive soils existing on Crete and active encouragement of deforestation in the Bronze Age period.

Homer provides evidence of the cutting of timbers for ship-building when Odysseus describes the death of Sarpedon, “as falls an oak or silver poplar, or slim pine that on the hills the shipwrights fell with whetted axes, to be timber for shipbuilding” and the noise of the battle Odysseus describes, “as the din of woodcutters in the glades of the mountains (Homer ca 850 BC).

Aristole (384-322 BC) also wrote on Mycenaean land degradation and changes “at the time of the Trojan War, the land of Argos being swampy, it could only feed a scanty population, whilst the land of Mycenae was good and therefore highly prized. But now the contrary is the case, for the latter has become too dry and lies untitled, whilst the land of Argos, which was a morass and therefore lay untitled has now become good arable land” (cited in Kraft et al. 1977). This quote refers to a time 1000 years before Aristotle’s own life and indicates that sedimentary alluvium that buried the swamp lands has improved their land capability, while the lands at Mycenae have suffered erosion and are now droughty. It would appear that the Ancient philosophers pondered the decline of the Bronze Age Greece as much as we today ponder and research the impacts of Classical and Roman Greece.

Today approximately fourth-fifths of Greece has thin skeletal soils. In earlier times the hill and mountain slopes were moderately well forested and a rich source of timber and game (Plato 427-347 BC-b). Although Plato (427-347 BC-a) indicates Athens itself was not “rich in timber suitable for the easy construction of a navy” (cited in Hughes 1983) i.e., deforestation had left Athens with meagre forest cover.

From the evidence of Homer and Hesiod (ca. 700 BC) it seems that Greece was self-supporting so far as primary goods are concerned (Kitto 1963). Homer describes in the Odyssey VI and VII (cited in Kitto 1963) orchards, vineyards, vegetable gardens well watered by springs. Homer shows us that Odysseus’s father, Laertes, tended the vines while his mother Penelope wove cloth. While Odysseus himself boasts he can drive a furrow as straight as any man (cited in Kitto 1963). This indicates the great
industry and independence of the Greek people and the practical nature of the leaders and statesmen.

Plato (427-347 BC-b) was a disciple of Socrates, who established the world’s first University in Athens following the death of Socrates. Plato made numerous comments on soil fertility and erosion issues for example “all other lands were surpassed by ours in goodness of soil, so that it was actually able at that period to support a large host which was exempt from the labours of husbandry” (Plato 427-347 BC-b). Here Plato is commenting on the highly arable and fertile nature of the soils at Attica (Athens region). Today this is referred to as land capability assessment, and it appears that some of the lands in southern Greece were of high agricultural capability. Today lands of higher capability class require less management inputs such as fertilisers, drainage and soil conservation, and they have high versatility of use (Noble 1992). Today recognition of such valuable lands allows for their protection by various methods of soil conservation and restrictions on urban development and other infrastructure.

However Plato (427-347 BC-b) continues in his description outlining the land changes “when it was still un-ravaged, it had high hills instead of bare mountains and the plain now called Phelleus (meaning stony) was a plain for deep rich earth. And there were great forests on the mountains, indications of which are still to be seen: there are mountains which now support nothing but bees, but it is not long since timber was cut from them for the roofing of the largest buildings, and these roof-timbers are still sound. Moreover, there were tall-cultivated trees in abundance, and the mountains afforded pasture for countless herds.” Here Plato is discussing the loss of tree cover and loss of good pasturelands, now heavily degraded. He is also discussing the siltation problem in the lowlands that buried prior alluvial soils with stone and gravel. He also points out that fertile soils covered all the high hills in the region and that they were highly productive pastures. Plato indicates timber was in great demand for construction of buildings and also naval and trading ships (see Plate 2.6). Other demands on the forests and woodlands included tree cutting for household heating, firing pottery and roof-tiles as well as pollarding trees for stock feed (Forbes and Koster 1976). Although Plato does not state the loss of soil was a direct result of tree clearance, the association is quite clear.
Plato continues to extol the productivity and versatility of the local soils, despite their apparent prior degradation (427-347 BC-b) “and of its goodness a strong proof is this; what is now left of our soil rivals any other in being all-productive and abundant in crops and rich in pasturage for all kinds of cattle; and at that period, in addition to their fine quality, it produced these in vast quantity.” With this comment Plato is suggesting that the degraded soils of Attica (region around Athens) were still better than degraded soils elsewhere. Modern examples where both erosion and structural degradation of highly arable soils has not reduced their productivity are discussed by several authors (Sparrow et al. 1999; Cotching et al. 2002a; Cotching et al. 2002b).

Plato (from the Critias 427-347 BC-b) tells us of the almost total loss of soil in Attica due to the local topography “during these nine thousand years (not to be taken literally) many severe storms have occurred, and the soil swilled away from the higher regions has not formed, as it has in other places, any alluvial plain worth mentioning, but has been washed away everywhere and lost at the bottom of the sea, so that what is left, just as in the small islands, compared with what existed then is like the bones of a body wasted with disease: the fat and soft soil has fallen away, leaving only the skeleton of the land.” Plato here is commenting on the loss of soil at Attica to the deep sea as occurred on Crete and other Greek Islands without the formation of an alluvial plain which occurs elsewhere. The name “Attica” means – “the sea all around it is deep” (Kitto 1963). Hence the loss of “fat and soft” soil is most catastrophic. This type of erosion is a major issue in present-day Tasmania as the highly arable red ferrosols lie on hill slopes which descend to Bass Strait (Sparrow et al. 1999; Cotching et al. 2002b; Isbell 2002).

A telling factor of Ancient agricultural decline can be seen in the change in diet, alluded to by Kitto (1963), between Homeric and classical Greek times. In Homer the heroes eat an ox every two or three hundred verses while fish was a token of extreme destitution. In classical times fish is seen as a luxury and meat becomes less commonly mentioned (Kitto 1963).

The philosopher and poet Luceretius (96-55 BC) believed the earth was dying and that the land had become exhausted and that the rains and rivers were carrying it to its
burial in the sea. Clearly an expression of concern over active soil erosion at that
time, and a reduction in productivity of the remaining eroded and depleted soils.

A letter from the Bishop of Carthage, St Cyprian AD 250, raises the issues of soil
depletion and droughtiness (cited in Carter and Dale 1974). I quote, “you must know
that the world has grown old and does not remain in its former vigour. It bears witness
to its own decline. The rainfall and the sun’s warmth are both diminishing; the metals
are nearly exhausted; the husbandman is failing in his field…springs which once
gushed forth liberally, now barely give a trickle of water.” St Cyprian is clearly
concerned about soil decline due probably due to nutrient depletion caused by
excessive cropping and grazing. He also suggests the climate/weather has changed
toward both cooler and drier conditions. Whether the reduction in spring discharge
relates to loss of soil and tree cover or the drier climate is not indicated. Certainly
earlier Greek philosophers had linked degradation of mountain springs to loss of soil
and tree cover (Vitruvius 90-20 BC; Plato 427-347 BC-b).

The degradation of soil and forest resources had impacts on the Greek city-states or
Polis. Thucydides (471-400 BC) provides a quote from Alcibiades of Athens to the
Spartans “we sailed to Sicily [intending to build] many triremes (fighting ships) in
addition to our own, as Italy has timber in abundance”. Sparta, Athens and Rhodes all
used treaties and diplomacy to secure timber supplies for naval requirements
(Polybius 200-118 BC; Xenophon 444-357 BC; Thucydides 471-400 BC).

Money raised from a new vein of silver in Laurion (east Attica) enabled Athens to
buy timber from Italy to increase her fleet from 40 ships in 489 BC to over 200 ships
in 480 BC (Xenophon 444-357 BC). The polis paid for the ship and its crew:
equipment and repairs were paid for by a rich citizen as one of the liturgies
(trierarchia - a brilliant Athenian notion which shamed the richest citizens into
spending their wealth on the city, without the need for taxation).

Thucydides (471-400 BC) tells us the Athenians “were greatly alarmed by the capture
of Amphipolis. The chief reason was the city was useful to them for the importation
of timber and ship-building” (cited in Hughes 1983). Certainly this hints at the great
regional demand for timber and its decline in Attica around 450 BC.
Summary

The problems of deforestation were recognised by some governments, and actions were taken to re-establish and also protect forests. Aristotle tells how hyloroi or “Custodians of the Forests” who supervised some forests had “guard-posts and mess-rooms for patrol duty” (quoted in Hughes 1983). Modern forest-reserve agreements, e.g., the Tasmanian Regional Forest Agreement, also aim to control and supervise logging and thus ensure sustainable use of the forest resource (Tasmanian Forest Practises Board 2003). While Thucydides (471-400 BC) indicates that in Cyprus “the Kings used not to cut the trees. . . because they took great care of them and managed them” (cited in Hughes 1983). Some governments also oversaw large afforestation programs such as in Ptolemaic Egypt (Rostovtzeff 1941). Some states also ordered the conservation of forests on private lands with laws and fines controlling fires, permission to cut timber and requirements for replanting. Land holders also saw the benefits in trees for shade, fodder, fuel, lumber but also for leisure and escape as parks and hunting reserves (Cato 234-149 BC; Theophrastus 327-287 BC; Collumella ca 60 AD).

However, perhaps we have not learnt from the ancients, as the following quote indicates (from Wace and Thompson’s account given in Moody and Rackham 1988); “they cut the trees recklessly and wastefully and allowed sheep and goats so that young pines had no chance of coming to maturity … So the destruction proceeded till the slope of Gorgol’u was bare and then came redistribution. The trees being away the melting snow and the heavy rains descended unchecked on Samarina, threatened to sweep away the village, and carved out the deep ravine already mentioned destroying houses and gardens. Not till then did Samarina awake to its danger and so some fifteen or twenty years ago it was decreed that no one should cut trees in K’urita or pasture beasts of any kind there under pain of heavy fine. Since then the wood has grown up thick and strong, the destruction has been averted and pines will in time reclothe the slopes of Gorgol’u”.

In summary a clear picture of Classical, Hellenistic and Roman Greece emerges from the writings presented above. It suggests soil erosion by water was active on sloping lands and of concern to the state or polis, but the increasing shortage of timber
reserves had more immediate economic and security implications. It seems the naval
power was critical to ensuring a supply of resources as local supplies became
degraded. This seems to drive cutting of timber further, for ship-building but also the
spoils of war led to increasing population and wealth and thus the demand for wood
for fuel, charcoal-ceramics industries and construction demands.

A hazier picture of similar environmental mismanagement associated with the Bronze
Age Greece also emerges through the writings of Homer and Egyptian hieroglyphics.

**Interpreting land and soil use in the past**
The aim of this section is to review papers that cover (1) soil properties and soil usage
in the past, (2) the nature of past soil landscapes and (3) land-use factors influencing
soil degradation in the past.

**The use of fire**
Human impacts on managing the land extend back into the Palaeolithic with the use
of fire. Williams (2003) indicates fire was the first great environmental force used by
man. Fire helped clear land and promoted and maintained the growth of favourable
plants like grasses, tubers, wild fruits, hazelnuts, sunflowers, wild rice, bracken,
cassava and blueberries (Williams 2003). Fire also aided hunting by manipulating
game and reducing the need to stalk and travel in dense forest. Mellars (1976) has
shown that controlled burning can alter species composition and increase yields of
browse forage and herbaceous forage in deciduous forests by 300 – 700 percent. This
increased game by up to 400 percent (Mellars 1976). A summary of the opportunistic
and pre-determined use of fire by early hominids is provided by Clark and Harris
(1985).

Fire may have been important in leading to the cooking of foods, which can help with
the reduction of toxins and antagonistic bacteria and/or fungi. Cooking also softens
harsh plant fibres, all these factors improved human health and hence population
(Williams 2003). Fire would also fortuitously lead to metallurgy and ceramics.
Ultimately, the control of fire may well have heralded the progressive domestication
of species of plant and animal, which led to development of agriculture and sedentary
rather than nomadic life styles (Williams 2003).
Homer had also written of the use of fires in Greece “through deep glens raged fierce fire on some parched mountainside and the deep forest beneath, and the wind, driving it, whirled everywhere the flame”. Loss of forest and other vegetation in such fires must have had significant implications for rainfall run-off and hence soil erosion. Wallbrink et al. (2004) have shown the very dramatic impacts of forest fires on accelerating soil erosion in the Mediterranean environments of New South Wales, Australia.

**Soil utilisation by the ancients**

Yassoglou and Nobeli (1972) in the work on the Merssini Project in southern Greece indicated the key ways soils were disturbed by humans in the Bronze Age included erosion, deposition, excavation and re-filling and ploughing. Erosion can remove part or all of a profile. Deposition will bury a profile, which may later be identified by its distinctive dark humic A horizon or structured and coloured B horizon (Yassoglou and Nobeli 1972). Yassoglou and Nobeli (1972) determined that the Bronze Age peoples used only the best soils for agriculture, even if they were some distance from the village. Bronze Age people, unlike modern inhabitants, constructed their houses on well-drained competent soils – this prevented moulds and illness. Where hill soils were used, they chose to cultivate the fertile clay loams developed on limestone rather than less fertile and more erosion-prone sandy soils (Yassoglou and Nobeli 1972). Clearly ancient people assessed land suitability and when possible chose the most fertile and versatile soils. Such soils will require the minimum of management inputs, including a reduced requirement for soil conservation works, as shown in modern soil and land capability mapping (Noble 1992).

Semple (1931) makes it clear that the ancient Mediterranean populations knew about soil chemical and physical management though the use of manuring, green manure crops, fertilisers, marling (liming), tillage rotations and fallowing.

Neolithic farmers preferred small areas of fertile, water-retentive, fine-textured soils (Sherratt 1980). Sherratt (1980) suggests that agriculture was limited to areas of moist soils close to springs, and at the confluence of streams, valley bottoms, lake margins, and now submerged coastal plain. Silty-clay soils and natural springs are
common in the Leipsokouki valley of Grevena (Doyle 1990). Sherratt (1980) also indicates the scratch plough was not introduced into the Mediterranean until the 3rd millennium BC (Sherratt 1980). Thus the impact of Neolithic land use on the environment was likely to be small, with Neolithic farmers using small areas of highly productive soil capable of producing good yields with the minimum of inputs. Agricultural expansion of locally high populations is seen to come from splitting of groups and movement into smaller and smaller patches of high-yielding land (Sherratt 1980).

Van Andel and Runnels (1995) indicate human exploitation of woodland did not occur until 4,000 years ago in Greece. Exploration on terraces and foothills did not occur before the Bronze Age. However, soil erosion due to human exploitation is responsible for both historical and Neolithic alluviation. Van Andel and Runnels (1995) discuss the suitability of light-textured alluvial soils developed on levee banks for cultivation, despite the difficulties of seasonal flooding. They suggest the back-swamps with heavier, waterlogging-prone, clay soils would have been used for grazing. They attribute the high human populations on the plain at Larissa to be due to the abundance of free-draining, light-textured on levee-bank soils. Buildings and dwellings were placed on elevated habitation mounds to reduce the impact of seasonal flooding. The selection of only certain high-capability soils for agriculture is used by Van Andel and Runnels (1995) to explain why population pressures on some areas would have been more intense than today, where the full range of soils can be utilised due to mechanised farming and modern fertilisers.

Seymour and Girardet (1986) comment on the change in burial customs of Minoans between 1700 and 1400 BC, when, due to lack of suitably large timbers for wooden coffins, people were buried in earthenware. Seymour and Girardet (1986) contend that removal of vegetation fuelled by an agricultural economy led to soil erosion and environmental decline during the middle Bronze Age. This degradation of resources, Seymour and Girardet (1986) suggest, undermined the economy of the Minoan civilisation leading to its decline. Seymour and Girardet (1986) comment on the few remaining pockets of soil in hollows and lowlands derived from pre-existing hill soils now eroded to barren rocky land. It is in these isolated patches where modern
farming is undertaken and the fertility of these small patches hints at the moderate to high fertility of the early Minoan landscape (Seymour and Girardet 1986).

Soils are a resource for plant growth but also for ceramics, foundations, bricks and living areas (Morris et al. 2003). The distribution of different soil types across the landscape has a big impact on human behaviour in both respect to resource procurement and adaptability. Morris et al. (2003) use soil mapping and identification of buried soils to reconstruct the landscape history of locales near two archaeological sites on the island of Crete. The authors noted Minoan pot sherds in the Kavousi 2 pedon and indicated the soil was radiocarbon dated to 3,000 yr BP but that the soil exhibited very little soil development. This was put down to the dry Mediterranean climate since the mid Holocene. Soils with redder clayey B2 horizons are thought to be due to Late Pleistocene weathering and aeolian accession. The key feature of the soils that affects land suitability and use is their capacity to absorb and store winter-dominant rainfalls (Morris et al. 2003). Soil moisture retention is affected by the soil structure, field texture, soil-regolith depth and stone content (Hillel 1998). The silty clay-loam textures and strong pedality of the soils in the Leipsokouki valley indicate they have high storage capacity of plant available water (Doyle 1990).

The elected leader of Athens, Solon (died 559 BC), encouraged agricultural specialisation in Attica due to the thin soils incapable of growing corn. He promoted grape vines and olive-oil production (Kitto 1963). He also forced land reform, ordering the redistribution of land from large estates to peasant farmers with large mortgage debts. Bruckner and Hoffmann (1992) describe how Attica (province around Athens) during the Classical Period (5th and 6th centuries BC), was famous for olive oil production, which was traded for grain as far away as the Ukraine. The olive groves were grown on terraces supported behind thick walls (0.8-1.4 m), today they are grown on slope without terraces. Bruckner and Hoffmann (1992) suggest this ancient technique was to improve soil-moisture retention and curb soil erosion in the semi-arid environment.
Pre-mechanised agriculture in Grevena

In the Nomos of Grevena Aschenbrenner (1988) has undertaken a study of the agricultural system prior to 1940. He indicates the pre-mechanised agricultural economy of Grevena was of a peasant subsistence type with most households not producing a surplus (Aschenbrenner 1988). The households produced a great diversity of products including wheat, barley, maize, rye, beans, chickpeas, vegetables, fruits, nuts, table grapes and wine. Oats, barley and several legumes were grown for stockfeed. Stock typically included a pair of oxen or horses for ploughing, a mule or donkey for transport, cows (variable number perhaps 1 or 2), pigs (1-2), chickens (10) and sheep/goats (15-30). These produced meat, milk, cheese, fat and offspring (Aschenbrenner 1988). Fallowing was limited by shortage of land and generally restricted to the poorer soil types. Prior to 1917 ploughing was by wooden ploughs similar to that described by Hesiod (ca 700BC). Fertilisation with animal-pen manure was limited to the poorer soil types. Irrigation was generally restricted to vegetable gardens close to springs or perennial streams. Wheat yields as measured by seed: harvest ratios were given as 1:3 but up to 1:5 in good fields (Aschenbrenner 1988). This subsistence living was commonly supplemented by other work such as wood cutting, working as a muleteers and associated trading, milling cereals, charcoal making, lime or tile making and agricultural labouring.

Soil erosion and depositional studies from Mediterranean environments

Introduction

This section will examine and discuss the causes and types of erosion in Mediterranean environments as well as examining the stratigraphic record to show the causes and timing of erosion-deposition events that have occurred during the Holocene. Such a review will provide a means of comparison with the dating, classification, and interpretation of the deposits examined in the current study.

Stream incision and hill slope erosion occur due to either destabilisation of deep regolith due to seismic activity, landscape denudation by fire or drought, or increase in the precipitation and run-off rate. The last two factors lead to an increase in stream power and erosion rate (Schumm 1977; Schumm 1991; Goudie 1995). After the study of approximately 1500 catchments around the world Wilson (1973) indicates it is very difficult to imagine a single variable that may be used to explain the variations
in sediment yield. However, if one were to be selected it would be land use rather than climate. Walling (1987) in a study of 1,500 catchments classifies most of Greece as having catchments with high (>500 tonnes/ha/yr) suspended sediment load. He put this down to climate, in particular intensive precipitation events. Dearing (1991) indicated erosion rates have generally increased since the deforestation of Mediterranean lands some 5,000 – 2,000 years BP. The rate of erosion accelerated in a series of increments as new technologies and land use practices were introduced. Goudie (1993; 1995) indicates Mediterranean environments are climatically aggressive and engender high rates of erosion. He also indicates the forest cover has several positive effects all of which reduce erosion rates;

1) Forest cover reduces raindrop impact
2) Forest humus layer or litter leads to high infiltration rates
3) Rich soil fauna increases macro-pore abundance that are able to conduct water deeper into the soil profile
4) Commonly forest soils have strongly aggregated soil matrix
5) Tree roots stabilise soil on the slopes.

Macklin et al. (1995) indicate Mediterranean environments are the most susceptible to increased sediment yield resulting from anthropogenic impacts - see Figure 2.11 from Dedkov and Moshzherim (1992). They also indicate that the erosion rate increased dramatically when any type of vegetation cover is reduced below 70%.

Hughes (1983) has shown that in the Kuk swamps of Papua New Guinea the naturally low erosion rate increased ten-fold following forest clearance (increased from 1.5 mm/yr to 12 mm/yr). This erosion rate then stabilised prior to a 20-fold increase following the introduction of coffee plantations by Europeans.

Goudie (1995) indicates the erosion rate in several catchments in the USA have doubled for every 20% loss of forest cover. He also suggests that human causes of erosion relate primarily to deforestation, agriculture, construction, war and mining. The size and frequency of mass-movement events in particular increase following deforestation, while the erosion rate under agriculture depends on ground cover, timing and type of tillage and size of fields on any given site. These findings
highlight the impact tree clearance may have had in Greece with its rugged
topography and aggressive climate.

Vita-Finzi (1969) published a comprehensive book on the late-Quaternary stream
history for the entire Mediterranean basin. In this work Vita-Finzi proposed that two
major phases of alluviation had occurred, which he named the Older and the Younger
Fill. Each had silted up stream channels, valleys and coastal plains that had been
incised in earlier erosional phases. The Older Fill, which has red hues, is dated at ca.
50,000 - 10,000 years BP, while the Younger Fill, with yellow and brown hues, is
dated to late Roman - early modern times (post c.a. AD 400). Both deposits are
attributed to climatic factors. Van Andel (1990) believes Vita-Finzi’s model is either
too simple or erroneous as applied to the Greek landscape. The older alluvial deposits
described and in part dated by Doyle (1990) are not reddish in colour. Rather they are
grey or light olive-brown. Doyle (1990) found soil redness in the study area was
more strongly related to soil parent material differences than soil age.

model. Bintliff attributes the Younger Fill to climatic changes between the middle 1st
millennium AD and late medieval times. The Older Fill (red beds) he believes relates
to higher rainfall periods than occurred during the early or middle part of the last
 glaciation.

Erosion and deposition studies from the Peloponnesus and Attica
Recently Fuchs et al. (2004) have undertaken a fascinating study that examines
colluvial deposits on slopes dated by thermoluminescence in the NE Peloponnesus.
They indicate Holocene colluvial activity related to human disturbance in a semi-
continuous manner during the last 7,000 years. Colluvial activity began with
Neolithic farming, but strong periods of activity occurred in middle to late Bronze
Age, the Roman period, and the period since the sixteenth century. They found no
traces of in situ soil formation and thus conclude there were no periods of landscape
stability in the last 7,000 years. Thus they conclude that human activity was the
dominant factor in the Holocene landscape. The use of colluvial deposits in addition
to the many studies of alluvial deposits is a strategy used in the present study. After
Plate 2.7 Classical harbour of Ephesus, now 4 km from the sea due to historical river alluviation (Roberts, 1998, p191).

Figure 2.6 Shows ancient city of Ephesus and the various ancient shorelines as the Gulf of Ephesus infilled with alluvium. Note the Late Ancient shoreline and the attempts at dredging to keep the harbour open before the city was finally abandoned.
all, it is the erosion on the hill slopes that feeds the alluvial aggradation events on the valley floor.

Yassoglou and Nobeli (1972) examined soil profile morphology at the Bronze Age site of Messinia. They were able to show the impact of humans in increasing spatial variability of soils and the magnitude of impact on truncation of soil profiles. Later burial of these truncated profiles led to the development of polygenetic profiles, such as alfisols buried by younger materials. The buried and now truncated profiles would have required a stable landscape for their development. However, erosion could be shown to have buried and/or degraded the soils, leaving only remnants of the Bt and C horizons. Similar results of truncation and burial of mature soil profiles are reported by Doyle in Grevena (1990) and by Dennell and Webley in Bulgaria (1974).

In the Peloponnesus Pope and Van Andel (1984) undertook a study of landscape erosion and deposition in the late Quaternary. They used soils as stratigraphic markers and examined differences in soil features such as texture, colour, structured B horizons, and pedogenic carbonate to gauge soil age. With increased soil age they identified increases in abundance and thickness of clay films, increased degree of soil structural development, increased development of precipitated pedogenic carbonate, and increased redness of the soil profiles due to weathering and release of iron oxides. These increases in soil development with age confirm the relative ages of the seven alluvial units.

The three Pleistocene alluvial units identified by Pope and Van Andel are linked to climatic fluctuations, although no alluviation was seen to accompany the very dramatic climate change associated with the close of the last glaciation. The Southern Argolid landscape appeared to remain stable from 20,000 to 4,500 years BP. This is in contrast to the current study and to the work of Demitrak in Thessaly (1986). However, after 4,500 years BP debris flow deposits become widespread and aggradation occurs in the valleys due to the hill slope destabilisation. The authors indicate that this is probably due to extensive Early Bronze Age land clearance (Pope and Van Andel 1984). A stable period followed the later Bronze Age, the dark ages and the early historic period. It came to an end with a brief phase of alluvial aggradation between 300 and 50 BC. Slopes appear to have remained stable through
the late Roman despite considerable expansion in the settled area. A poorly dated late phase of debris flow deposits occurs approximately after AD 1000 and subsequent events vary across catchments and continue to the present.

Pope and Van Andel (1984) identify a range of alluvial features useful to review in the light of the current study. A key unit is the radiating alluvial fan. Older fans are capped by younger alluvial material. Alluvial units have been subdivided into upper and lower units based on buried soil layers (Pope and Van Andel 1984). The stratigraphic units identified are as follows:

1. Large cobbles and boulders supported in a fine-grained matrix are identified as debris flow deposits.
2. Sand, gravel and cobbles with variable amounts of fine-grained matrix, clast-supported with little to no imbrication are identified as braided stream-channel deposits.
3. Discontinuous planar, laminated sand, gravel and cobbles with little to no matrix are identified as stream flood deposits.
4. Lenticular imbricated sand, gravel and cobbles with variable amounts of fine-grained matrix are identified as braided stream channel deposits.
5. Planar cross-bedded sand and gravels are identified as forset beds of braided channel bar.
6. Pebbly, sandy loam little or no bedding, with occasional pebble stringers are identified as overbank distal fan deposit.
7. Sandy loam little or no bedding are identified as overbank distal fan.
8. Buried soil horizon, often truncated.
9. Bt soil horizon.
10. Pedogenic carbonate horizon often truncated.

This list of stratigraphic materials can be summarised into five key depositional facies:

1. **Facies A - Debris flow materials** consisting of poorly sorted angular to sub-rounded gravels, cobbles and boulders in a fine matrix.
2. **Facies B – Channel and braided stream deposits** consisting of poor to well-sorted sands, gravels and cobbles in massive deposit. Lenticular or plane-
laminated tabular beds. Sedimentary features such as scour beds and cross-bedding also occur.

(3) Facies C – Overbank and distal fan deposits consisting of poor to well sorted sandy loams with occasional pebble beds (stringers). Soil profiles usually develop on the upper part of the sedimentary sequence.

(4) Facies D – Hydraulic or colluvial slope mantle consisting of silty loams with varying amounts of matrix-supported angular pebbles and cobbles, forming on slopes. Lag deposits associated with buried soils are common.

(5) Facies E – Periglacial slope deposits rare and associated with proximal fans emanating from limestone peaks over 400m. Consists of lenses of well sorted, angular rock chips of pebble size.

The facies identified above are deposited or formed in a number of specific sequences as a landscape undergoes a stability shift. The facies are deposited in sequences from A-B-C to A-C or B-C. The contact between A and B is described as commonly erosional, that between A and C or B and C are depositional. Contacts between sequences are usually erosional. In the Argolid each sequence ends with Facies C – this is not the case in Grevena, where Facies D commonly finishes the sequence. Following this, soils begin to develop and the streams may then re-incise. Pope and Van Andel describe the modern stream channels as being deeply incised, as they are in Grevena (Doyle 1990). They describe Facies A and B as varying significantly from one phase to the next, where as Facies C is ubiquitous. In the Grevena region Facies D and C are both common, and facies B and A are more variable.

In the Southern Argolid simple correlations with climatic events do not seem to explain adequately the soil-forming and erosion-deposition events. The chronology instead matches the decline of key periods of human exploitation of the landscape. Pope and Van Andel (1984) examine natural causes of erosion/destabilisation, particularly the role of tectonics, base-level change and climate change as natural causes of accelerated erosion and depositional periods. During the last 10,000 years, however, they see human activities as paramount. That have involved in the domestication of animals and plants, forest clearance, ploughing, terracing and grazing – all of which can have major impacts on the landscape. The key human impact is modification of the vegetation cover. Loss of cover due to clearing and
overgrazing can enhance soil erosion and run-off. Cultivation generally depletes soil organic matter and reduces soil structure (Butzer 1974), leading to increased run-off and erosion. On the other hand soil conservation through terracing and gully check dams reduces runoff and catches soil on the slope.

Pope and Van Andel (1984) suggest the neglect of the terrace systems, which are put in place to conserve the soil, is a key cause of accelerated erosion. This neglect is associated with a change from cropping to pastoralism. The stock denudes the slopes and physically damages the soil terraces. Total abandonment of an area, however, leads to maquis vegetation returning stability within 10 years or so on the slopes (Naveh and Dan 1973). However, Forbes and Koster (1976) indicate that if terrace maintenance is forgotten and cultivation and grazing continue, erosion on terraced hillsides can be catastrophic. Jameson (1978) has shown that terracing of a slope requires much effort for little return. This means a change to less labour-intensive pastoralism and olive production that could set the stage for soil erosion. Erosion would be accelerated by the collapse of soil terracing due to grazing animals clambering over the walls. However, the use of terracing does not seem to be a major factor in either the modern or ancient agricultural system in the Nomos of Grevena (Aschenbrenner 1988). Thus any accelerated erosion in that environment cannot be related to the collapse of terracing.

Van Andel et al. (1986) emphasise the role of human activities on soil erosion, as the various erosion events across the Mediterranean are not synchronous, and dates do not match those of Vita-Finzi (1969). Erosion appears to follow clearing of slopes by fire, cutting and clearing of forest, and grazing pressure. Van Andel et al. (1986) highlight the fact that soils can only develop during periods of landscape stability. During landscape instability soil erosion, debris flow deposits, colluvial aprons and various alluvial deposits are formed. The length of the landscape stability will affect the degree of soil development. Longer periods produce deeper, more weathered soils.

During the last 100,000 years, the Southern Argolid landscape was mostly stable. Streams were incised, soil formed, and sedimentation occurred mostly on the coast. Only three brief episodes of erosion and sedimentation occurred in the Pleistocene. A
key finding is that during the deglaciation the landscape remained stable. This is in disagreement with data from Doyle (1990) in Grevena. Van Andel et al. (1986) conclude the Palaeolithic, Mesolithic and Neolithic settlements had no measurable impact on the landscape, a factor reviewed in the current study. Van Andel et al. (1986) discuss a sequence of erosion and depositional events that begin 4,500 years ago, approximately 1,000 years after land clearance began in earnest. They put this erosion down to increased clearing of slopes and increased population density. Two later events laid down stream-flood deposits. Van Andel et al. (1986) conclude that due to lack of evidence for increased rainfall, run-off or other circumstances, the cause of this was due to neglect of well established systems of terracing and gully check dams.

Both Van Andel et al. (1986) and Runnels (1995b) define two methods of slope stabilisation: terracing and dam construction on slopes, and complete abandonment of land to allow maquis and pine to resettle fields. They conclude that two modes of stabilisation and two modes of destabilisation of slopes occur:

Modes of stabilisation;

1. Use of an adequate system of terracing and gully check dam (ancient soil conservation management).
2. The complete abandonment of farming, allowing the return of maquis and pine to stabilise the slopes.

Modes of destabilisation;

1. Neglect of soil conservation in combination with pastoralism during times of economic depression.
2. Careless clearing and increased cropping cycles during times of economic expansion.

Van Andel et al. (1986) and Runnels (1995b) describe debris flow deposits in the Southern Argolid as chaotic beds of ill-sorted, largely angular boulders, cobbles and pebbles, surrounded by a matrix of finer material. They suggest they were deposited catastrophically as thick, water-rich slurries that occurred following sheet erosion of weathered slope mantles. In the Argolid there are single debris flow deposits that
cover an entire valley floor to several metres thick, indicating they are quite significant erosional events. This definition of debris flow deposits will be used in the current study. Van Andel et al. indicate runoff that becomes concentrated in gullies, greatly enhances down-cutting. This has implications for sediment transport and incision in the present study.

**Summary of depositional events in the Southern Argolid**

1. Early Holocene landscape stability during Neolithic occupation.
2. 2700-1400 BC severe and catastrophic erosion associated with deforestation as indicated by pollen data. Debris flows caused by land clearing and cereal cultivation – implies that agriculture was expanding onto hill slopes.
3. A long stable period followed this, perhaps due to spread of *maquis*, as indicated in pollen record during the Early Helladic to Mid Helladic decline. Subsequent Mycenaean expansion, Dark Ages depopulation, or Archaic and Classical (500-250 BC) expansions did not disturb the landscape, and this is put down to the use of soil conserving land management practices.
4. From the end of the Classical Period (500-250 BC) through to the Hellenistic Period (250-50 BC) high runoff, gullying and sediment yield occurred.
5. Stability returned in the prosperous Late Roman Period (AD 400-600), this continued in the Early Byzantine (AD 600-1000) despite land abandonment indicated by an increase in *maquis* and pine pollen. This is followed by debris flows and alluvial deposition approximately around AD 1000.
6. From approximately AD 1700 to present in some valleys alluvial aggradation has occurred.

Van Andel et al. (1990) determine that erosional episodes in the headwaters and slopes of several valleys in Greece resulted in alluviation on valley floors and small coastal plains. Van Andel et al. (1990) indicate that each unit ends with a loamy textured soil profile that suggests that erosional-depositional cycles ended with stable phases allowing soil formation. During the phase of soil profile development streams incised and sedimentation basically ceased. The age-related characteristics of the soils are used to correlate depositional units from one valley to the next. In summary Van Andel et al. (1990) identified three key types of sediment: (1) chaotic, ill-sorted gravels in a fine matrix as typical debris flow deposits, (2) stratified well-sorted sands...
and gravels laid down by streams, (3) sandy loams formed by overbank deposits. The debris flow deposits are seen in the upper parts of catchments and are taken as evidence of catastrophic sheet erosion. These were the result of reduced plant cover due to human activity or a decline in precipitation. The stream-flood deposits form when gully cutting is enhanced by increased run-off (this would lend support to the idea of human causes, as drought would prevent the gullying?). These stream-flood deposits dominate in the middle catchment. The overbank deposits are the result of floods and are most common in the lower catchment and on the coastal plain. In the Leipsokouki catchment Doyle (1990) noted sections with all three types of deposits, all having a capping of soil colluvium.

Zangger (1992b) summarises erosion-deposition studies from Greece and comes to the following conclusions. In both Thessaly and the southern Argolid rapid climate change occurred at the end of the ice age but this did not cause landscape destabilisation. This seems at odds with the findings of Demitrack, who describes an alluvial deposit dating from 14,000 - 9,500 years BP. Zangger indicates that no floodplain alluviation occurred in Thessaly at 27 - 7 kyr BP and at 32 – 4.5 kyr BP in the Southern Argolid. This finding is surprising given the glacial and peri-glacial activity in the Pindos and Peloponnesus Mountains (see Figure 2.11) (Denton and Hughes 1981 311). Zangger suggests that a soil one-meter thick on marl could form in a few thousand years in Greece. However, he fails to provide information on the chemical weathering and leaching that might be expected in such a time frame. The author doubts this rapid rate of soil formation but is happy to accept that one metre of soil may be deposited by colluvial processes in such a period. He highlights the role of rainfall as the key element influencing local soil fertility. Certainly in a semi-arid environment like much of the Mediterranean soil moisture storage will be a major factor affecting crop growth; however soil depth and texture affect just how much of the rainfall may potentially be stored in the soil. Past forests would have made streams more perennial in nature rather than the ephemeral flash-flood streams of today. But surely the steppe vegetation of the late glacial will have also led to more ephemeral flash-flood type stream behaviour and thus alluvial aggradation. Macklin et al. (1995) indicate the rainfall distribution during glacial conditions had greater seasonality, with greater winter rainfall capable of flash-flooding.
Zangger (1992b) believes the transformation of woodland into farmland was probably largely completed in the Early Bronze Age. Already the Mycenaean vegetation looked similar to the present; certainly by the Classical period full agricultural potential of land had been attained. Clearing and deforestation, grazing, farming and man-made fire are the most important causes of accelerated erosion (cited from Forbes and Koster 1976). The most pervasive environmental changes in the Agrive Plain occurred in the Late Neolithic and Early Bronze Age, and then later landscape stability allowed soil profiles to develop on the Bronze Age alluvium, which was deposited approximately five thousand years ago (Zangger 1992b).

Pope et al. (2003) have studied the development of alluvial fans near Sparta and have shown the link to both human-induced land use change and climatic fluctuations. It seems some of the recent arguments favour a combination of climatic and anthropogenic factors as the cause of some of the erosion-deposition events seen in the Mediterranean during the Holocene (Wagstaff 1981; Chester and James 1991; Ballais 1995; Pope et al. 2003; Fuchs et al. 2004).

**Erosion and deposition studies from the Aegean Islands**

Davidson (1980) points out that if a detailed sedimentary chronology can be established, then factors that induced the soil erosion can be postulated. For example, if a phase of erosion was a synchronous event throughout Greece the emphasis might be given to regional climatic change. Davidson suggests progress can only be made if a detailed chronology of sedimentation, tectonic events, changes in climate, base level, and vegetation as well as for the spread of man's activities can be established. Davidson (1980) discusses Bintliff's (1976) work on the size of the Thermic Gulf which in the 6th millennium BC occupied most of the present plain, with limited sediment deposition by the Haliakmon, Moglenitsa, Axios and Gallikos Rivers. However, following the 5th century BC until the 5th century AD a marked reduction in the size of the gulf occurred due to rapid sedimentation by these rivers.

Erosion in the modern Melos landscape is very apparent, slopes are characterised by the virtual absence of soil cover, and lithosols are common across the island (Davidson 1980). Terracing has been used in recent times to prevent erosion. In many valleys there is a sharp discontinuity between rocky soils and extensive valley
fills (Davidson 1980). The stratigraphy of these fills on Melos reveals that they contain Classical or later sherds and a building dating to ca. 300 - 0 BC has been buried by the fill (Davidson 1980). These data suggests extensive alluviation was well under way by late-Classical times – this only weakly agrees with Vita-Finzi’s (1969) younger fill, which is late Roman to late Medieval. However, Davidson (1980) has shown from a deep well section that older fills are buried within the Melos landscape – at approximately 3 m depth he found Late Bronze Age (ca. 1500-1100 BC) fill materials. These are capped by materials containing both Bronze Age and younger materials. This site and further stream channel sections show that hill slope erosion was underway on Melos by 1000 BC. Further work on Santorini shows that degraded rocky soils existed on the hillslopes, which were buried by ash and pumice at the close of the Minoan civilisation in ca. 1470 BC (Davidson 1980). This is despite a period of 15,000 years without volcanic activity prior to the eruption that buried the city at Akrotiti. This should have allowed sufficient time for fertile soils to develop on the island in pre-Minoan times (Davidson 1980). The indication is the Minoans caused soil degradation. Davidson’s use of soil stratigraphy involving the study of soil development, soil burial and soil profile truncation is very instructive, and these methods have been employed in the current study.

French and Whitelaw (1999) describe the use of soil micro-morphological techniques for examining soil features to determine mode of deposition and soil formation processes on the island of Amorgos in the Cyclades. They use the presence of dusty laminated and non-laminated clay coatings in the soil pores and matrix to identify the timing and degrees of soil disturbance. They discuss the role of agricultural terracing of slopes in the Late Bronze Age following catastrophic erosion in the Early Bronze Age. French and Whitelaw (1999) examined sediment sections and found that erosion and sedimentation was episodic rather than continuous, based on the presence of stable soil formation interrupted by distinct periods of rapid deposition. The erosion events occurred in the Early Bronze Age (ca. 2800-2200 BC), the Hellenistic period (ca. 300-0 BC) and the Recent Past (ca. AD 1850-1990). Lag deposits form important stratigraphic markers, and they appear to have protected soils in slope depressions. They relate erosion to the expansion of grazing and vegetation clearance. They also indicate that the stabilisation of slopes by vegetation can occur in decades (Rackham and Moody 1992; Jameson et al. 1994). Erosion has been
blamed on deforestation on the island of Naxos that occurred in the later Early Bronze Age (Dalongeville and Renault-Miskovsky 1993). French and Whitelaw (1999) also note that the increase in fortified sites in the later Early Bronze Age may also indicate competition for suitable agricultural lands and possibly reflect a degradation of existed occupied environments.

**Erosion and deposition studies from Epirus, Macedonia and Thessaly**

Sivignon (1988) provides a pictorial representation of the progressive infilling of the Thermic Gulf from the Neolithic to AD 1900, with the greatest rate of infilling in the Greco-Roman to Late Roman period (Figure 2.10).

Evidence for large floods in the Pindos Mountains during the Late glacial period has been provided by Woodward *et al.* (2001). Fine-grained slackwater sediments were preserved beneath the Late Upper Palaeolithic deposits at Boila rock shelter in the Voidomatis River basin (Woodward *et al.* 2001). The central and upper part of the flood sediments were deposited between ca. 14,300 – 13,900 \(^{14}\text{C}\) yr BP during the global cooling associated with Heinrich event 1. X-ray diffraction and X-ray fluorescence work on the alluvial slack-water sediments have assisted in determining the provenance of sediment (Woodward and Goldberg 2001; Woodward *et al.* 2001). The studies of Boili and Klithi rock shelters have employed field stratigraphy supported by chemical and micro-morphological examination to fingerprint sediment and determine depositional histories (Bailey *et al.* 1999; Woodward and Goldberg 2001; Woodward *et al.* 2001).

Macklin *et al.* (1997) have indicated four alluvial units in the Voidomatis basin in Epirus dating from >150,000 years BP (Kipi Unit), ca. 30,000 – 24,000 years BP (Aristi Unit), ca. 24,000 – 20,000 years BP (Vikos Unit) and 1,000 years BP (Klithi Unit) (Macklin *et al.* 1997). The authors indicate climatic fluctuations as having the strongest effect on the Late Pleistocene units but give no causal factor for the late Holocene unit.

At Drama, Lespez (2003) described three distinct phases of stream aggradation, soil erosion and landscape stabilisation over the past 7000 years. While little erosion occurred in the Neolithic and Early Bronze Age, erosion and alluvial sedimentation
accelerated during the Late Bronze Age (3600-3000 BP). Even greater rates of erosion occur in the Antique and the Early Byzantine Era (3rd century BC-7th century AD) and more significantly in the Ottoman period (beginning of the 15th to the 20th century AD). The low levels of alluvial aggradation recorded during the Late Neolithic and the Early Bronze Age (7400-4000 BP) are related to the fact that the early farmers preferred to cultivate soils on the gentle more stable slopes (Lespez 2003). During the Late Bronze Age, the land use pattern changed. The less stable soils on the foothills came under cultivation and were susceptible to erosion. These are tied to long-term land use changes and also increase sensitivity of the degraded landscape to climatic changes. Lespez (2003) believes the early-historic deforestation and agricultural activities rendered river systems more sensitive to relatively modest changes in climate.

**Erosion and deposition studies from other Mediterranean locations**

Roberts (1998) provides evidence of the filling of the harbour at Ephesus (see Plate 2.7 and Figure 2.6), while dating by radiocarbon and artefacts indicates rapid alluviation in the Hellenistic to Late Roman period. Eisma (1978) examined the siltation of the magnificent harbour at Ephesus. Between 750 and 300 BC the Kucuk Menderes river pro-graded only 1 km, while between 300 and 100 BC it moved forward rapidly over 5 km. The pro-gradation rate decreased again in Roman and Early Middle Ages times moving forwards 2 km between 100 BC and AD 200 and 1.5 km between AD 200 and 700 (Plate 2.7 and Figure 2.6).

Bruckner and Hoffmann (1992) provide examples from Rhevma Livadonas (8 km west of Cape Sounion), where a river terrace has formed from the deposition of alluvium. It contains ancient pottery from Classical times in the lower and middle section, while in the upper part and on the soil surface Late Roman fragments occur. They conclude, that the build-up of the alluvium began with erosion of materials from the surrounding hills during and after the Classical era and terminated in Late Roman times (Bruckner and Hoffmann 1992). They suggest that some erosion may have begun in the high population Classical times (5th and 4th century BC) but probably increased during the subsequent agricultural decline and neglect of man-made terraces on slopes. Once the terracing of slopes began to fail, rapid and catastrophic erosion would have occurred, and the soil protected behind the walls became exposed to the
heavy Mediterranean rainfall events. They explain the cessation of erosion to a new equilibrium and maquis and garrigue vegetation that developed (Bruckner and Hoffmann 1992).

Bruckner and Hoffmann (1992) also examined sites in Italy on the Basilicatan rivers of Bradaon, Basento and Cavone (area formerly called Lucania). They determined four periods of sedimentation. By using both radiocarbon dating and identification of artefacts they showed sedimentation was first associated with climatic and sea level changes in the mid Holocene (Sediment 1). Later sedimentation (Sediment 2) was associated with intensive settlement, deforestation and agriculture during the time when Southern Italy was part of Magna Grecia and later Imperium Romanum (Bruckner and Hoffmann 1992). The Great Greek colonization of Southern Italy from the 8th century BC led to the foundation of many cities (e.g., Taranto, Metaponto). At about 550 BC hundreds of farmlets existed in the hinterlands of Metaponto, and coins of the day portrayed an ear of grain, indicating the importance of agriculture. Sediment 2 contains artefacts from the Great Greek Era, while the uppermost section contains Late Roman roof tiles. Bruckner and Hoffmann (1992) conclude erosion ceased in the Late Roman period as the ecosystem stabilised following latifundia decline from the mid 3rd century AD (reported in Seneca’s work “lucani saltus”).

During the Middle Ages they note that another phase of soil erosion and sedimentation (sediment 3) occurred following settlement of hilltops and the renewal of land cultivation (Bruckner and Hoffmann 1992). This sedimentation and erosion ended following tectonic or political changes between the 11th and 15th century AD. The net effect of these three phases of erosion was a terrace consisting of Sediments 1, 2 and 3 deposited on top of each another. A second terrace has since formed by incision into these materials following deforestation associated with population pressure since the middle 19th century. A peak of 500,000 inhabitants occurred in 1851 and sub-aerial erosion has resulted in silted valleys and seaward progradation that peaked at 8 m/year between 1873 and 1949 on the Agri and Sinni (Bruckner and Hoffmann 1992). The authors also provide an example of erosion of the hill slope and alluvial progradation on the Iberian Peninsula during the last 500 years, particularly during the Reconquista, when Catholic Kings expelled the Arabs. The erosion may have been assisted by the higher rate of torrential rainfall during the “Little Ice Age” between 1500 and 1750 AD (Bruckner and Hoffmann 1992).
Bruckner and Hoffmann (1992) point out that the rainfall in the Mediterranean climate can come in intense falls with up to one third of the annual rainfall in one 24-hour period. Often the rainy season begins following the droughty summer period, when soils are vulnerable to erosion. In addition the geological youth, tectonic activity, unconsolidated materials and steep topography make much of Greece and other Mediterranean sites highly vulnerable to erosion. This environment was thus susceptible to the disturbance of man and much of the erosion and sedimentation, particularly during the late Holocene, is interpreted as anthropogenic.

By 270 BC almost all of Italy was at the command of Rome. In the series of Punic wars, ending in 145 BC, Rome took Sicily and the Carthage in North Africa, which provided a wheat basket to meet the expanding needs and a slave labour source for estate farms. Greece, Syria and Asia Minor later fell to Roman rule (Seymour and Girardet 1986). During Roman expansion large numbers of farming citizens were required for soldiery. Noblemen of Rome became rich landlords with slave labour. The Roman law, which allowed land lying neglected to be legally claimed, provided another avenue for the rich landowners to increase their holding as smaller landholders were called to arms. Timber was also required for ships and buildings from the hinterland hill country, leading to the deforestation of the Apennines during the Punic Wars (Seymour and Girardet 1986). Ponde Marshes formed at the mouth of the Tiber River due to erosion in the hillsides near the end of the Punic wars. Also the harbour at Paestum near Naples became completely silted-up along with many other Italian harbours in pre-Christian times (Seymour and Girardet 1986).

Dearing (1994) examined the chalk downs of England. He noted they had suffered from anthropogenic erosion for much of the last 5000 years. Dearing (1994) provides a sketch of sediment stores and sinks in natural landscapes on soft and hard rock types (figure 11.1 in Roberts 1998). The model shows the interlinking of elements in a landscape with eroding, transporting and depositing areas which are similar to the ideas of Butler (1959). These features can be seen in the Leipsokouki landscape, where eroded slopes, transported colluvial deposits, depositional debris and alluvial deposits occur. Work by Dearing (1991) shows that prior to 3000 years BP erosion at
Lake Busjosjo in southern Sweden was derived from topsoils, whilst erosion during the last 3000 years has been derived from subsoil materials.

**Comparative studies of erosion and deposition**

Diamond (1986) reminds us of the history of global environmental damage, in particular deforestation, caused by humans with an extensive list of examples; in the Pacific deforestation and extinctions occurred in New Zealand, Easter Island, The Cook Islands, Marquesas and Mangareva Islands, and in the Americas degradation and decline occurred in the Mayan civilization and the Anasazi civilization at Chaco Canyon. These examples add weight to the anthropogenic cause as paramount in environmental degradation and extinctions seen in the Mediterranean, the Middle East, Madagascar and Australia (Diamond 1986).

However, May (1991) reminds researchers of a-priori assumptions made when examining the causes of Holocene erosion in the western Mediterranean. He identifies periods of colluviation that took place during periods of socio-economic expansion. These include late Neolithic and Bronze Age, the Roman period and at the end of the Middle Ages. However, May (1991) concludes that the parallels between anthropogenic activity and the erosion event point to human disturbance of the landscape as the most logical cause.

Benito (2003) provides an examination of alluvial aggradation from 37 sites across the Mediterranean region. He discusses the role of climatic changes as a key to the understanding of Mediterranean erosion during the period 40 – 10 kyr BP. Data for the Maghreb zone (North Africa) provide evidence of alluvial silts and sands being deposited between 38 and 26 $^{14}$C kyr BP, between 26 and 13.9 $^{14}$C kyr BP and finally between 15 – 10 $^{14}$C kyr BP (17.9 – 11.5 cal kyr BP). This later deposit may correlate with the Syndendron alluvium (ca. 14-10 kyr BP) but the earlier deposits are not represented in the Leipsokouki valley (refer to Chapter 5).

Benito (2003) describes an early Holocene alluvial deposit from eastern Maghreb and southern Tunisia. This deposit appears to be in the age range 7 – 10 cal kyr BP. Alluvial deposition above a distinct paleosol in site P37 of Doyle (1990) may correlate with this early Holocene activity. A “very low Historic terrace” is also
reported in the region, having beige or grey colours. However the timing of this is poorly constrained with its age ranging from 1.2 to as much as 3.3 cal kyr BP. Despite the poor and varied timing Benito (2003) correlates this with climatic factors and the driving force with enhancement by human modifications. The variations in dates for commencement of this deposit appear to contradict climatic factors as key drivers. The spatial and temporal variations in the nature of this deposit suggest localised human impact is a more likely casual factor as shown by Van Andel et al. (1990) and Wagstaff (1981). The very high rates of sedimentation commonly associated with these late Holocene deposits also implicates an accelerated erosion process, typically associated with human interference (Doyle 1990; Fuchs et al. 2004). A “very low Post-Islamic” terrace has been dated to ca. 600 years BP and this is correlated to the transition from the Medieval Optimum to the beginning of the Little Ice Age. This would appear to contradict a direct climatic cause.

Benito (2003) indicates cold-dry climatic periods (glacial) result in rapid run-off due to supposed “unvegetated surfaces”. No evidence of lack of vegetation cover is provided and it is well demonstrated that steppe vegetation, typical of periglacial environments, is equally resistant to sheet and rill erosion as forested land (Morgan 1977). Thus it is difficult to associate accelerated erosion with cold-dry climate unless one is talking of glacier induced erosion and rapid deposition of outwash alluvium and associated loess deposition.

Macklin et al. (2002) provides a summary of dated alluvial deposits from 200 kyr to 10 kyr BP and they emphasise the climatic factor as the main driver of river aggradation. Their theory suggests cool-dry climatic periods lead to a reduction in forest cover with a subsequent increased hill slope erosion and valley aggradation (Macklin et al. 2002). While this is accepted for a large part of the Pleistocene, Late Pleistocene and Holocene events are made increasingly complicated by the introduction of human activities. The arrival of Palaeolithic people and increased firing make it more difficult to implicate climate change as the sole cause of alluvial aggradation during the last 20,000 years. Also data on sheet wash and rill erosion do not support greatly enhanced rates of erosion under grassland cover than forest cover (Morgan 1977). The loss of vegetative cover through fire, cultivation, drought or
construction has a greater impact of these types of water erosion. Debris flows and other forms of mass movement are the more likely result of deforestation.

In summary quite a number of studies have been carried out in the Mediterranean basin and they appear to provide different chronologies for alluvial aggradations events. Surprisingly few studies have closely examined the processes and deposits on the valley slopes (Fuchs et al. 1994 a notable exception); instead they have largely focused on the valley fill deposits. The current study will try to improve on this weakness by examining the slopes to try and determine the links between the valley fills and the slope deposits and processes. Other weaknesses of some previous studies include the poor dating and reliance on artefacts and archaeological structures for dating. Poor chronologies and reliance on artefacts can lead to circular arguments of cause and affect, i.e. the deposit contains Hellenistic sherds, it must be ca. 2,200 years old, Hellenistic people probably have caused the erosion. While an equally valid interpretation may be that the deposit contains Hellenistic sherds, it may have been deposited anytime post Hellenistic, and its cause may be seismic, climatic or anthropogenic. Also the reworking of artefacts and charcoal into younger deposits may mean time lags of several thousands years (Lang and Honscheidt 1999) – thus multiple dated sites and stratified sites are needed; this has been a key objective of the current study.

**Soil stratigraphy and use of paleosols and sedimentary evidence**

The interpretation of soil stratigraphic sections can provide detailed information on landscape stability and instability through time. However, care is needed in the description, mapping, and interpretation of buried soil layers to avoid misinterpretation and also to get the most from the available data. Work by Bruce Butler and his team of pedologists in Australia and work by R.V. Ruhe and R.B. Morrison in the USA has provided some important guidance in this area (Butler 1959; Butler 1967; Ruhe 1975; Morrison 1978; Wright 1986). Some of this work is reviewed here in the light of the abundance of buried soil-like layers in the study area.

Butler (1959) used pedoderms (“soil-skins” both buried and relict soils) to identify pre-existing ground surfaces in Australian landscapes. By identification of a sequence of stratified soils and sediments a history of soil formation separated by periods of
erosion or accelerated deposition can be identified. Key techniques for separation of materials must meet one of four essential criteria (Butler 1959). They are (1) proving the separateness of a soil layer by tracing continuity over a diverse range of substrates i.e., a soil formed in a loess mantle capping several different substrates (2) the vertical extent and limits of variation of a soil layer maybe shown by (a) the “principle of association” i.e. materials regularly found in association with a layer may be presumed to comprise several parts of the one layer unless found separated at any point and (b) the unity of patterns of variation down a soil profile with a change from one soil layer to another indicated by a repetition of distribution patterns, (3) the horizontal extent and limits of variation of a soil layer being set by the way it contacts other layers, and (4) relative placement of layers or the law of super-position (Butler 1959).

Morrison (1978) introduces the idea of the geosol or soil weathering profile as a time-stratigraphic unit in Quaternary stratigraphy. The geosol is similar to Butler's "pedoderm" or ground surface. It represents a weathering profile (soil) that formed during a period of relative landscape stability, consisting of a sequence of soil horizons, i.e., A, B, C.

Weathering to form soils cannot normally take place during intervals of rapid deposition or erosion due to lack of time. The episodes of weathering occur during relatively stable periods at the site of soil formation. Cycles of landscape stability-instability were named K cycles or time cycles (K comes from Greek _Kronos_ [χρόνος] or time) by Butler (1959; 1967). The sequence of soils and sediments proves the intermittence of weathering and erosional/depositional cycles.

The geosol or pedoderm is not an original deposit, but rather forms on pre-existing material _in situ_. In this way it is similar to a hydrothermal or metamorphic alteration zone or facies. However, soil materials may be transported by creep and sheet wash, leading to soil-material layers that may not be considered geosols or pedoderms. Thus the _in situ_ weathering and leaching features of a soil profile must be demonstrated to prove a period of landscape stability. Soil formation can only start after the development of a land surface, by either erosion or deposition (Jenny 1941). Erosion-deposition and soil formation events may be periodic, i.e. cyclic in time,
providing layered stratigraphic field sections. Buried soils or paleosols indicate periods of; 1) stability that allows the weathering and soil formation to occur, and 2) preceding erosion or deposition that forms the surface or sediments from which the soil develops.

An important consideration, particularly involving disturbance by man, is that the erosion and deposition may not affect all of the landscape. Areas may exist beyond the zones of deposition and erosion in which the original soil mantle still exists. Butler refers to these as "persistent zones", and they will have relict soils, i.e., on the ridgelines and elevated preserved land surfaces. At these sites one expects to find the most deeply weathered soil profiles.

A pedoderm or geosol comprises the soil profile and the surface of one K cycle (Butler 1959; Butler 1967). Deposits may provide evidence of the type of past climate and causes of instability. In the erosional zones the ground-surface may be cut across bedrock units of varying age or older soils or weathering profiles, as in the current study. In the depositional zones the surface will comprise the uppermost section of the sedimentary deposit. Each component of the ground-surface should be determined in character and its mode and environment of deposition established. This type of study may reveal the conditions prevailing/causing the deposition/unstable phase (Butler 1959; Butler 1967). Such techniques are very useful in determining landscape histories in complex soil landscapes like the study area.

Periodic landscape activity may cause erosion and deposition to occur at different places across a landscape resulting in characteristic zones. Each ground surface may thus have up to several components or zones defined, viz non-eroded or persistent, eroding, depositing and alternating areas. Butler defined these as follows (1959).

(1) Persistent zone - areas not been eroded or buried in one or more K cycles. The soils in these zones are older and may be considered relict in the terms of Morrison (1965).

(2) The erosional zone - where erosion has occurred in one or more cycles and when older soils have been removed and where fresher substrate materials are exposed for new soil development.
Depositional zone - where sedimentary material buries pre-existing soils and new soils develop on the newly deposited materials. These depositional materials may be loess, alluvium, colluvium, etc.

Alternating zone - where both erosion and deposition have occurred in one or more K cycles, may have truncated, part soils and composite soils.

A pedoderm may not be uniform laterally and may vary considerably due to topographic impact on site drainage, or in soil texture due to facies changes e.g., channel – levee – near floodplain – distal floodplain sedimentary relationships. Thus it may be difficult to tell one pedoderm from another due to natural variation in soil properties through the landscape. Hence the need to try and trace soils laterally where possible.

The Leipsokouki catchment contains evidence of many buried soils. These are indicated by their darker colour, the development of soil structures, the higher level of soil organic carbon, the presence of vertical rootlet and root pores or pedo-tubules (Retallack 2003) and in many cases the presence of roots and ferruginised roots. In situ soil profiles also have abrupt upper boundaries and diffuse or gradual lower boundaries. The upper boundary of buried soils is often marked by abrupt textural changes along with fabric and structural changes.

Although the organic carbon in some buried soils is not as high as the levels seen in the modern surface soils, Retallack (2003) has indicated paleosols may lose up to 90% of their carbon as measured by the Walkley-Black method. However, the dark colour, structure, and other pedogenic features of buried topsoils commonly remain. This allows tracing of certain buried soil mantles through the landscape to provide more certainty of their pedogenic nature. While the soil drainage may change the same soil surface can be traced to represent a period of stable soil forming conditions.

**Interpreting the soil and sediment stratigraphy**

Once the soil stratigraphy has been determined, dating and interpretation is the next step. Butzer (1982) discusses the use of potsherds and archaeological structures in providing a maximum age for a deposit i.e., a particular deposit can be no older than the youngest archaeological material it contains. He also warns that despite increased awareness of both spatial and temporal complexity there remains a tendency to over-
simplify geomorphic evidence. Butzer (1982) highlights the need for close examination of the morpho-stratigraphic sections involving; “longitudinal gradients, vertical and lateral patterning of facies, disconformities of soils and relationships between stream sediments, colluvia and slope forms. This need to examine both the slope process and deposits and the valley floor fills is commonly not undertaken. Butzer (1982) suggests that if there are adequate temporal and spatial controls, which are the objectives of the current work, it may be possible to consider the potential role of climatic change, human activities, or a host of other environmental variables to determine how they affect ground cover, run-off’, and sediment supply and mobilisation.

Examples from Central Europe indicate cut-and-fill cycles after 3,500 years BP have been significantly affected if not controlled by human activities, while fluvial readjustments just after 5,000 years BP are more difficult to relate to human activities (Butzer 1982). This is supported by alluviation in lower Austria which began at 4,850 years BP when the area was not yet settled (Butzer 1982). In the Mediterranean Butzer indicates “post –Classical” deposits as being spatially related to Roman agricultural and settlement areas. He indicates that widespread colluvial deposits commonly grade into heterogenous alluvial fills. This situation is typical of the current study area. Post-Medieval as well as Roman deforestation and agricultural expansion in marginal environments appears as the causal factor in the Mediterranean (Butzer 1974; Butzer 1982). Indeed whenever found, the “post-Classical” deposits are the most “conspicuous geomorphic feature in the Holocene Landscape” (Butzer 1982). The Mediterranean region was one where early to mid Holocene alluvial materials may occur, but the key pattern is one of accelerated erosion due to human misuse of the land. This begins at a local level in the Bronze Age but becomes more extensive in post-Classical times. Although climate may have played some part, the extent, scope, and both temporal and spatial variability of the slope and valley deposits implicates humans as the key cause (Butzer 1982).

In summary the key immediate variables affecting catchment behaviour are (1) ground cover, (2) runoff, and (3) sediment supply. The ultimate variables are (1) climate and (2) human activity (Butzer 1982). These variables certainly seem to be the main issues in the Mediterranean where there is a long record of human activity
and a climatic regime that makes any denudation of the hilly countryside very susceptible to erosion. Thus in this study a review of recent pollen cores is undertaken to get an indication of the climatic history and the timing of the introduction of anthropogenic species. The research study attempts to determine periods of high sediment supply and associated aggradation vs periods of incision related to higher stream flow and lower sediment supply. Starkel has used such information to model stream behaviour in central Europe (Starkel 1983; Starkel 1987; Starkel et al. 1991; Starkel 2003). This will also be aided by examination of marine cores, which provide information on paleo-climate and continental sediment supply.

Patton and Schumm (1981) have demonstrated that gully erosion in the semi-arid western United States occurs through nick-point recession upstream. Erosion occurs at the nick-point and in gully sides, but erosional reaches are separated by both aggrading and stable channel reaches, i.e., various parts of the system may behave in different ways. Sediment is produced by erosion from gully walls and nick-points, may collect in the wider channels downstream. Thus sediment is transported in an episodic manner. Therefore in catchments with high sediment supply and high discharge, episodic transport and deposition can lead to complex alluvial chronologies without obvious correlation to climatic or human controls (Patton and Schumm 1981). This gully erosion pattern discussed by Patton and Schumm may apply to the study area, where gullies are migrating through nick-point recession and sediment accumulation is very dependent on valley width, confluence of tributaries, and sediment supply from the valley sides (Doyle 1990).

Starkel (1983; 1987; 2003) developed a model of fluvial activity for the temperate zone of Europe, based on the premise that climatic fluctuations were reflected in parallel changes of river discharge (Qw) and sediment load (Qs). Depending on the leading factor (rise of Qw or Qs) during an active phase, there follows a tendency to either erosion or aggradation (Starkel, 1987). However, he was forced to admit that deviations from this climatic model in the late Holocene (<2.5 kyr BP) are explained as being "...phases of increased fluvial activity that are reflected by the up-building of flood plains due to accelerated (anthropogenic) soil erosion" (Starkel, 1987). Starkel (2003) indicates accelerated soil erosion at several sites in southern Poland due to tree clearance by early Neolithic peoples at about 6 kyr BP. This continued in to the later
Neolithic as evidenced by alluviation in larger valleys. More extensive alluviation is associated with the late Bronze Age and Roman periods in southern Poland, Germany and the Czech Republic (Starkel 2003).

In summary the issues raised that require addressing in the interpretation of the current study are (1) the need for a comprehensive chronology of colluvial and alluvial events, (2) a clear characterisation of their properties and mode of deposition, (3) a review of climatic and environmental conditions in the area (pollen records, sediment records), and (4) a clear record of human populations or activity.

Holocene pollen record relevant to the region of study

Introduction

This section will bring together a summary of the pollen record from core sites close to the study area. The pollen record is important for several reasons:

1) It provides an approximate vegetation record in the region and thus provides a history of environmental and climatic changes.

2) Pollen cores provide information on sedimentation rates in the local region.

3) Pollen cores can show the history of burning of an area as charcoal accumulates in low parts of the landscape.

4) Pollen cores can show both the introduction and record of domesticated plants and thus indicate anthropogenic modification of the environment.

One of the difficulties with the use of pollen data for the interpretation of climate history is the interference of humans since at least the Neolithic (Kuniholm 1990). Kuniholm provides several examples of the difficulty of interpreting climatic impacts on economic and environmental degradation in the last 100 years, a timeframe where we have very good written records; indeed there is still argument over the actuality of the “greenhouse effect”. Kuniholm’s review of work in the Mediterranean and Middle East indicates minor fluctuations but no major climatic
Figure 2.7  Pollen diagram from Sogut SE Turkey, showing clearance phase after approx. 3,000 years BP (from Roberts 1998, source van Zeist et al., 1975).

Figure 2.8  Geomorphic reconstruction in the vicinity of Troy during the Holocene, showing that Troy was near the sea during the famous landing of the Mycenaean fleet in the Bronze Age as Homer described, since then rapid alluvial sedimentation in the bay of Troy has occurred (Kraft et al., 1980).
changes in the last 5,500 years BP in Iran or in the last 3,000 – 4,000 years in Turkey (Figure 2.7). In Mesopotamia Kuniholm found that increased aridity occurred after the 4th millennium BC.

**Pollen record from Greece**

Tzedakis (1993) has demonstrated the strong link between the pollen records of northern Greece (Ioannina [I-249] in Epirus and Tenaghi Philippion in Drama) and the marine oxygen isotope records of glacial – interglacial cycles. While never entirely treeless, the vegetation at Ioannina shows fluctuations between glacial open steppe dominated by Gramineae/Artemisia with some Pinus and the interglacial phases of oak forest dominated by Quercus with Ulmus, Caprinus and Abies increasing in succession. Although tree pollen is retained throughout the record, suggesting local refugia, the general pattern of open steppe alternating with oak forest is similar to records from France and central Italy (Tzedakis 1993). Galanidou et al. also show tree pollen records for I-284 core in Ioannina with the curve indicating a dramatic decline in oak after 5,000 years BP and again after ca. 2,300 years BP (2000). This record also shows a steady increase in arboreal pollen between 12,500 (ca. 14,500 cal yr BP) and 7,000 years BP, with a dip between 11,000 and 10,000 years BP – perhaps a Younger Dryas signal, as radiocarbon corrections do not appear to have been applied which would move this back to approximately 13,000 – 12,000 yr BP (Younger Dryas stadial is dated to ca 12.7 – 11.5 ka BP). The increase in arboreal pollen after ca. 14,500 years may reflect the Bolling - Allerod interstadial at ca 14.5 - 12.7 cal kyr BP (Chappellaz et al. 1993; Hughen and others 1998; Wilson et al. 2000; Mithen 2003). This interpretation indicates that not only are the major glacial – interglacial cycles of central and northern Europe represented in the pollen record but also some of the late glacial swings.

A pollen core from Lake Gramousti, approximately 60 km west of the study area, has a vegetational history extending back to ca. 15,000 years BP (Willis 1992a). The site lies on the western side of the Pindos Mountains at an altitude of 285 m. Uncalibrated dates are given in the paper and these are reported as uncalibrated years BP (as given below). The pollen record indicates at 13,200 – 11,200 years BP (ca 15 – 13 kyr cal BP) the vegetation was dominated by a steppe community of grasses and herbs (sedges, pig weed and sagebrush) with rare trees, apart from the regional
Figure 2.9 Summary pollen diagrams from Khimaditis, northern Greece, and Ionnina, northwestern Greece (from Roberts and Wright (1993) after Bottema 1974).

Figure 2.10 Diagram showing the alluvial infilling of the Macedonian plain during the late Holocene. The catchment under investigation is in the headwaters of the Haliakmon River (marked by the arrow). Source: - Sivignon 1988
presence of pine, oak, fir, juniper and willow (Willis 1992a). A small increase in trees occurs after 11,200 yr BP but this returns to treeless steppe between 10,300 and 9,800 yr BP (ca 12 kyr cal BP). After 9,700 years BP oak woodland becomes established with the steppe vegetation greatly reduced. However, high frequencies of grasses and herbs indicate open ground and an oak woodland canopy not very dense, rather a mosaic of trees, herbs and shrubs (Willis 1992a). Oak increases again after 8,700 years BP along with a decrease in herbs and grasses (ca 10.5 kyr cal BP). Between 7,400 and 5,200 yr BP there is an expansion of hornbeam, firs and birch and a decrease in oak that produces a mixed deciduous forest. Watts (1988) has suggested increased precipitation in the Mediterranean region at 7,500 – 5,000 years BP to explain the increase in fir, hornbeam and birch during this period. Willis concurs with this view. Between 5,200 and 4,300 Willis indicates woodland dominated by dense oak with fir and Phillyrea. Between 4,300 and 1,200 years BP fluctuations between oak woodland and a vegetation dominated by herbs and grasses with some oak indicate an increasing anthropogenic influence on the landscape (Willis 1992b). The lack of cultivars at Lake Gramousti is taken to indicate that the area, when disturbed, was used mainly for grazing rather than cropping. This led to tree clearance and a vegetation dominated by grasses and graze resistant shrubs (Willis 1992b).

In mainland Greece pollen records that cover the last few thousand years indicate human activity is a major factor influencing vegetational changes (Chester and James 1991). Late Holocene pollen diagrams from the Plain of Drama by van der Hammen et al. (1965) show dense forest dominated by Quercus and Pinus, but Tilia, Ulmus, Carpinus and Alnus also occurred before 7,850 ±50 BP. Sediment younger than 5,000 yr BP contain pollen characteristic of an open mixed oak forest of Quercus ilex/coccifera-Pistacia-Juniperus with Corylus and Ostrya. The oak forest becomes more open in the younger pollen zones indicated by increased Fagus and Ericaceae. The upper zone shows an increase of Pistacia and non-forest type pollen (van der Hammen et al. 1965).

Pollen data from Tenaghi Philippon on the Drama plain in northern Greece provide an important vegetation record from ca 7,500 – 2,800 ¹⁴C years BP (Greig and Turner 1974; Turner and Greig 1975). The site can be considered on the boundary of the Mediterranean and continental climate zones. The pollen record shows six
assemblage sub-zones (p – k) between the Middle Neolithic and the Classical periods. The oldest sub-zone (k) 6500 – 2500 BC shows mixed oak forest with Quercus-Tilia pollen. This then changes to mixed oak forest and thinner woodland with some maquis between 2500 and 1900 BC. The pollen assemblages indicating human disturbance begin at 1900-1350 BC with the olive pollen along with a decline in elm and lime. Dates for the zones (n-p) above are extrapolated and show an increase in weedy species with mixed oak forest at ca 1000-550 BC and then mixed oak forest with olive cultivation at ca 1000 – 550 BC. The last sub-zone shows moderate oak pollen with some thinner woodland and open land (Greig and Turner 1974; Turner and Greig 1975).

In summary, Greig and Turner (1974) have shown that a mixed oak forest existed on heavier soils at ca. 6500-2500 BC, with elm and lime on moister land and some hazel and ash in more open glades. The remainder of the Bronze Age at the Philippi site shows maquis vegetation signalling the spread of grazing. Clear evidence of vegetation change caused by humans comes from the period 1900-1350 BC as indicated by olive cultivation. During 1350-1000 BC there was a drop in olive pollen, but it increases again during 1000-550 BC. Thus the view that may be drawn from the record is that humans progressively increase their impact beginning from 2500 BC, but that there was little overall impact on the oak forests until post-Classical times (Greig and Turner 1974). This may indicate a greater agricultural focus on grazing in the region due to lower suitability for olive and grape.

In central Greece the site of Lake Kopais in the Boeotai region provides another pollen record (Greig and Turner 1974). The site has a more typical Mediterranean climate of dry summers and mild winters. The pollen core (zones K5 –K7c) is dated in the lower third on the K6/K7a zone boundary at 5,205 ± 120 years BP. The lowest zone (K5) shows high oak pollen with Juniperus and Pistacia with low amounts of herb and aquatic pollen (Greig and Turner 1974). This gives way to moderate amounts of oak with some being evergreen types in zone K6. The whole of zone 7 shows low levels of oak pollen. But zone 7a and 7c have high olive, herb and aquatic pollen while the intervening zone 7b has no olive. On the basis of pollen evidence from Lake Kopais and Drama Greig and Turner (1974) argue, that little evidence for major climatic change in the period from 7000 BC to the present.
Turner and Greig (1975) describe a pollen core from Limni Kopais on the southern mainland of Greece that provides a record from the late glacial to the late Holocene. The pollen core indicates oak woodland responded to the Bolling-Allerod late glacial climatic maximum of NW Europe, and oak was later greatly reduced in the late Neolithic (Turner and Greig 1975). The deepest pollen zone K1 shows typical Wurm glacial steppe vegetation (Artemisia, Chenopodiaceae and Gramineae) with few trees. The zone K2 shows more Sparganium and also mollusca shells, which are taken to suggest warmer and wetter conditions in the lake. The zone K3 shows a steady rise in tree pollen to 50% oak along with a rise in pine and juniper. Zone K4 indicates a drop in tree pollen and an increase in Gramineae pollen indicating a reversal of the forest development. This appears to correlate with the Younger Dryas stadial and increased soil erosion is indicated by a rise in the silt fraction (Turner and Greig 1975). This corresponds with the findings of Wijmstra (1969) and the zone Y3, which is shown to correspond with the Younger Dryas by radiocarbon dating. Zones K5 and K6 shows a return to high amounts of tree pollen, dominated by oak but with Juniperus and Pistacia. K6 has less Juniperus and Pistacia and Ostrya in low frequencies (Turner and Greig 1975). Grasses, herbs and open ground increase rapidly in zone K7, which is dated to 5,205 ± 120 (SRR-82). Both in the early and late parts of the K7 zone there are influxes of clay followed by peat formation. These suggest soil erosion on the slopes leading to the formation of deltas and shallower conditions suited to aquatic plants and the build-up of peat (Turner and Greig 1975). Two phases of olive cultivation also appear in zone K7.

Willis (1994) indicates the development of the present-day vegetation started at approximately 4,500 14C years BP with the onset of anthropogenic disturbance. Clearance resulted in the increase of open-ground herbaceous types and grasses. New trees become established included Juglans, Olea, Castanea and Platanus (Willis 1994). This occurred due to both importation by the Greeks and Romans but also due to favourable niches being created by anthropogenic disturbance.

Pollen records from central and southern Greece show a much greater impact with forest probably substantially reduced by Bronze Age (Wright 1972; Greig and Turner 1974). Wright shows changes in vegetation during the last 4,000 years are
attributable to humans. Sometime before the middle Bronze Age, pine woods disappeared probably due to wood cutting, while during the Mycenaean period the area was cleared for agriculture. From 1100-700 BC olives were widely grown and this continues with the rise and fall of cultural periods. Greig and Turner (1974) suggest the plains of Central and Southern Greece would have been a treeless landscape in the Bronze Age while the hill country of northern Greece would have remained largely forested.

Turner and Geig (1975) show that deciduous oak forest appears to be the climax vegetation of the post-glacial period. They also state there is no clear evidence in the pollen diagrams of major climatic change during the post-glacial. A key conclusion is that there exists a three thousand year difference between oak forest destruction at Kopais in southern mainland Greece and at Tenaghi Philippon near Drama (NE Greece). However, this does not mean the wooded landscape was not being utilised in other ways, e.g. for grazing oak woodland or oak pasture as indicated by Moody and Rackham (1988).

Wright (1968) indicates the Mediterranean climate during the last glaciation was one of semi-arid treeless steppe, liking it to Anatolia today with refugia of mixed oak forest in wetter mountain valleys. Wright (after van der Hammen et al. 1965; 1968) also indicates a treeless landscape for the lowlands of Macedonia and also for Ioanina (Mountains of NW Greece) during the last glacial period. A pollen diagram detailing the 7000 – 0 BC from the southern Dalmatian coast (400 km north of Greece) indicates the replacement of oak mixed forest with mixed woodlands of mesic trees and Mediterranean juniper at about 5600 BC (Beug 1967b). This is attributed to the mid-postglacial climatic optimum. After about 4300 BC the evergreen Mediterranean oaks spread into the area and dominated. Disturbance is indicated by introduction of cereal grains, nut trees, olive and Aleppo pine (Beug 1967b). Another pollen study starting at about 2000 BC from near Pylos in the Peloponnesus indicates high amounts of pine pollen (Beug 1967a). The pine decreases soon after 2000 BC and is attributed to clearance by the Mycenaean. There is also a rise in olive pollen from very low levels to approximately 40 percent at 1000-600 BC, suggesting a dramatic increase in olive cultivation in the Greek dark ages (Beug 1967a). Perhaps the olive was important to the subsistence in this period.
Beug (1975) indicates that the first human influence on the vegetation, indicated by pollen cores comes at the Greek to Roman period of about 500 – 0 BC on the Dalmatian coast, while in Macedonia the first human influence dates back to Neolithic times. Anthropogenic causes for the change in vegetation are indicated by a doubling of the *Juniperus* species and the elimination of summer-green trees. He blames overgrazing by cattle, goats and sheep for more than 7,000 years on the treeless landscape now present at Anzabegovo in northern Macedonia.

Willis (1992b) indicates post-glacial Neolithic settlers to Grevena would have encountered a landscape dominated by forest, especially oak woodland. Willis and Bennett (1994) argue on pollen evidence from the Balkans that extensive tree clearance did not occur until after about 6,000 years BP. It is not clear whether Bronze Age farmers in areas of moderate elevation would have needed to clear trees for agriculture and grazing. A site at Rezina marsh in Epirus close to Grevena shows a decrease in tree taxa from 6300 BP but particularly at 4300-3500 BP coincident with soil erosion from the flysch slopes (Willis 1992b; Willis 1992c). A second site at Gramousti in Epirus at 285 m A.S.L. shows oak woodland established in post-glacial time giving way to an alteration of oak woodland and open grasslands from about 4,300 BP (Willis 1992a). Willis also shows sediment yield in the pollen cores. At Rezina marsh sedimentation rate was very slow up until about 4,500 yr BP at 0.6 – 0.1 mm/yr. At 4,500 – 3,800 yr BP a period of rapid sedimentation occurred at 4.6 mm/yr. This rate drops to 2.1 mm/yr between 3,800 yr BP and about 3,100 yrs BP. Sedimentation rate then drops further to 1.2 mm/yr, and this rate continues until about 500 yr BP (Willis 1992c). Determination of sedimentation rates on the hill slopes and valley floor in the present study will be compared to the values reviewed here.

Wijmstra et al. (1990) indicate steppe-type vegetation with dry continental type conditions and cold winters in northern Greece during the glacial maximum. Open forests characterised by *Pistacia* developed during the early part of the interglacial phases of the late glacial indicating warmer and wetter conditions. This developed to evergreen oak forest where summers led to drier conditions and deciduous forest at cooler and wetter locations. Wijmstra et al. (1990) contend that winter conditions (rainfall) are more important in determining the nature of the vegetation than
temperature changes. They also argue that the maquis and garrigue vegetation are purely man-made, on the basis that their elements occurred in different climatic periods in the past (Wijmstra et al. 1990). Roberts and Wright (1993) report that at Tenaghi Phillippon oak increased rapidly at about 13.5 kry BP, while at high elevations (>500 m) the advance of oak forest was not complete until after 9 kyr BP.

In summary several important conclusions taken from this brief review are helpful in the current study. It appears that the dramatic climatic fluctuations during the close of the last glaciation are recorded in northern Greece. Open grassland conditions dominated in the glacial components, while oak forests occur in the interglacial cycles. Fluctuations between 15 – 10 kyr BP probably reflect the Allerod-Bolling interstadial and then return to cold-dry conditions of the Younger Dryas just prior to the warming and moistening of the Holocene period. If climatic change is a key driver of erosion-deposition cycles then these fluctuations should be reflected in the sediment record for all of northern Greece, and they are not (Demitrack 1986; Lewin et al. 1991; May 1991; Macklin et al. 1995; Woodward et al. 1995; Macklin et al. 1997; Woodward and Goldberg 2001; Woodward et al. 2001; Lespez 2003).

**Pollen record from Grevena**

*Kellia Fen*

The Kellia fen is at 580 m elevation and lies within the Leipokouki valley, 1.9 km NW of Grevena. The fen probably formed adjacent to a small stream. It shows two periods of alluvial deposition separated by a hiatus (Chester 1991). The upper layer spans 1230 AD to the present while the lower alluvial deposits are ca. 2,800 to sometime after 3,000 years BP. The presence of microscopic charcoal throughout the sedimentary sections indicates frequent fire history beginning dated ca. 830 BC in this sub-catchment (Chester 1991). Fires were uncommon at AD 1230 – 1320 but considerable regional and local fires appear at AD 1320 – 1370. Local firing declines until ca. AD 1650 after which firing peaks at regular intervals until the present. Variations in *Juniperus* reflect this history of fire (Chester 1991).

The regional pollen (AD 1230 – present) indicates an open canopy of deciduous/semi-evergreen oak woods. Generally high herb levels and presence of weeds typical of human disturbance since AD 1230 to the present indicate a low density of trees and an open landscape. Cereal pollen occurs throughout the upper alluvial layer (AD 1230 to present) but has a notable peak between ca. AD 1480 – 1580 (Chester 1991).
Chester indicates the ratio of deciduous to evergreen oak pollen suggests the coolest period in the valley is at about AD 1680, demonstrating good correspondence with the culmination of the Little Ice Age at about AD 1660 – 1680 (Lamb 1982; Grove 1988).

**Anelia Bog**
The Anelia Bog is located in Pindos Mountains at an elevation of 1440 m ASL and provides a record from AD 1560 to present. The site at Anelia shows the relationship between fire and deposition due to erosion on surrounding slopes. The core zones with most charcoal are associated with influx of sediment to the bog, with peat accumulating during periods of no burning. In summary, the record shows sediment deposition (silt, sand and fine gravel) with a brief peat accumulation period between AD 1560 and AD 1730, while after AD 1730 charcoal decreases and a thick peat accumulates (Chester 1991).

The most intense fires occurred between *ca.* AD 1585 – 1625 and AD 1625 – 1730. Local and regional fires decline after AD 1730 and peat accumulates. The period between about AD 1560 and 1730 has rapid coarse sedimentation and abundant herb species consistent with grazing in the neighbourhood of the site (Chester 1991). However continued abundance of herbs till AD 1920 associated with peat formation indicates fires and grazing combined are a greater cause of erosion than grazing without fire.

The decline of *Abies* after AD 1600 and its near disappearance after AD 1730 indicates lumbering was also part of the land-use system and may have also contributed to the erosion and sedimentation along with fire and grazing. Cereal pollen and weeds associated with human disturbance also occur throughout the sequence (Chester 1991).

**Gormara Bog**
The Gormara wetland site is the highest pollen core site in the Nomos of Grevena and is located in the Pindos Mountains at 1750 m ASL. The site has the longest record but reflects a sub-alpine site.
The core period from 1340 BC to AD 700 shows two periods of soil erosion separated by a small period of little or no erosion between ca. 80 BC to AD 330. This middle section shows very little sedimentation in the bog and very high organic matter with little charcoal (Chester 1991).

At 1340 - 890 BC the Gormara bog had high levels of inorganic matter indicating significant erosion of surrounding slopes. Abundant macro and microscopic charcoal indicate significant regional firing of the area (Chester 1991). Herbs, terrestrial grasses, weeds and minor cereals all suggest a landscape subject to grazing with minor local cereal cultivation. As with the data from the Kellia core in the study area, the Gormara core suggests an association between burning, grazing and soil erosion, this time somewhat earlier.

Between 890-480 BC erosion decreases as indicated by finer deposition but abundant macro and microscopic charcoal indicates frequent firing, while herbs suggest continued pastoralism. Between 480 BC and 80 BC soil erosion further declined as indicated by lower and more organic rich sedimentation. There is almost no charcoal. During the period 80 BC – AD 330 little erosion occurs and organic detritus accumulates in the bog. The period AD 330 to 700 shows erosion beginning again with high inorganic sedimentary deposition and increasing microscopic charcoal (Chester 1991). Burning of the catchment and regional vegetation after ca. reaches the levels of 1340 – 890 BC (Chester 1991).

In summary, Chester can show grazing and burning in the Pindos mountains between 1340 BC (or earlier) and 480 BC and then again from AD 330 to 700 or later. *Fagus* dominates in the Pindos between 480 BC and AD 330 and she suggests this may relate to human disturbance of the landscape as *Fagus* profits from impoverished abandoned lands (Bottema 1994). However, an alternative explanation maybe wetter conditions, which may have lasted from 3,200 – 1,500 yr BP (Bottema 1994).

_Erosion record for Grevena based on Chester’s findings_
Sedimentation record for Grevena after Chester (1991) indicates widespread burning and high amounts of inorganic sediment starting from at least 1340 BC. This is supported in the low land site of Kellia, where rapid sedimentation occurs at about 830 BC to approximately 600 BC. The sedimentation rate in the last 500 years was
approximately 3.4 mm/yr at Kellia (based on Figure 6.8 in Chester 1991). The Pindos site of Gormara shows sedimentation continuing until about 80 BC, after which peat accumulates in the mountain bog. After AD 330 to at least AD 700 and then again after AD 1330 firing and erosion are regular features of the landscape. At least in the mountains the mid to late Roman and perhaps middle Byzantine period produce little soil erosion.

_Paleo-climatic record_

**Introduction**

The local and global climatic record reconstruction is critical to any argument relating to erosion and sedimentation histories. Information comes from a number of sources;

1. Glacial advances provide a worldwide framework on the advance and retreat of valley glaciers during the Holocene. These provide useful climatic data of changes in precipitation and temperature.

2. Dendrochronology provides a long record on the growth rates at particular sites and can indicate periods of drought, rainfall and cold extremes.

3. Ice cores and sediment cores provide a record of oxygen isotopes, CO₂, methane, dust and sea level changes and thus detailed information about climatic changes during the last 500,000 years.

4. Lake-level changes provide information on variations in hydrology.

5. Soil development is affected by long-term climate, so changes in conditions can lead to a change in soil-forming conditions.

Climatic changes have been called upon to explain erosion and sedimentation histories and the collapse of ancient civilisations. One of the outstanding instances was that of Carpenter (1966). He ascribed the two dark ages of Greek history (Iron Age-Archaic and the Middle Byzantine) to increased droughtiness and famine leading to population collapse and abandonment of sites and a change to subsistence living. Carpenter discounts the Dorian invasion as the cause of the Mycenaean decline and instead favours climatic deterioration leading to an exodus and decline (Carpenter 1966). Lamb writes in support of the possibility of this view and describes possible climatic mechanisms (Lamb 1967; Lamb 1968; Lamb 1982). Wright (1968) discounts Carpenters (1966) climatic model for the Greek dark ages by showing pollen evidence from the Dalmatian coast, northern Greece and Turkey (van der
Hammen et al. 1965; Greig and Turner 1974; Turner and Greig 1975; van Zeist et al. 1975; Willis 1992a; Willis 1994) (see Figure 2.7). While the pollen records support the notion of a post Glacial climatic optimum in Greece and forest disturbance after about 4,000 years BP, they do not support a drier climate around 1200 BC as required by Carpenters model. Indeed the record from the Dalmatian coast indicates no significant climatic change from 4300 BC to the present (Wright 1968). However, Kuniholm (1990) presents the evidence for the decline of Mycenaean culture at about 1200 BC, including the cultural decline in Greece and western Turkey, incursions in Egypt and Mesopotamia, the Hekla 3 eruption (1100 ± 50 BC) and dendrochronological fluctuations centred on 1159 BC. Kuniholm concludes that the jury is still out.

Wright (1968) warned against correlations between central European climatic history and those of the Mediterranean. However, recent work on Italian lake cores and marine cores from the Adriatic indicate a strong link with the climatic history shown by the Greenland ice cores. This suggests a close coupling of the ocean-atmosphere system of the North Atlantic and the central Mediterranean (Allen et al. 1999). Allen et al. suggest there is generally less erosion during the forests biomes (interglacials), due to stable catchments, while steppe biomes suggest less stable soils associated with moderate aridity and seasonal drought. The aridity is thought to lead to temporal or spatial discontinuous vegetation (Allen et al. 1999).

The Balkans became densely wooded after the late glacial/Holocene transition and the Near East has been identified as open steppe in the early Holocene (Willis and Bennett 1994). The Late Pleistocene was colder and drier than today, and low densities of human occupation and many Greek studies indicate the landscape was stable during the late glacial – Holocene transition. Climatic models for northern Greece indicate the January temperatures were 10°C cooler with 40% less rainfall and this dryness led to steppe vegetation (Wright 1993). It was only in the highlands close to the coast where orographic rainfall allowed oak woodlands to occur (Wright 1993). Thus in northern Greece the lower slopes were tree-less because of the dryness and the colder temperatures lowered the tree line.
Wright (1993) also discusses the role of climatic change on the development of agriculture. In particular the fluctuations associated with the close of the last glaciation including the Younger Dryas stadial at \( ca \) 12.7 – 11.5 ka BP and the Bolling-Allerød interstadial at \( ca \) 14.5 - 12.7 kyr BP (Chappellaz et al. 1993; Hughen and others 1998; Wilson et al. 2000; Mithen 2003). Wright discusses the idea presented by Flannery (1969 cited in Wright 1993) regarding the broad spectrum of animal and plant resources including grinding stones for processing wild plants used by Mesolithic man prior to the development of sedentary agricultural systems.

A number of authors who have written on the recent Mediterranean erosion history have favoured climatic factors over human, tectonic, or base-level changes. These include Vita-Finzi’s (1969) study of Mediterranean Valleys and Bintliff’s (1975; 1977) studies in the Southern Agrolid. Vita-Finzi (1969) identifies only two Quaternary alluvial events, or valley fills and assigns climatic controls to both events. The younger fill being deposited between the late Roman and the Little Ice Age (ca. AD 1800) and the older fill to the last glacial maximum. Bintliff’s (1977) application of Vita-Finzi’s model to the Southern Argolid is at variance with the findings of Pope and Van Andel (1984) Van Andel et al. (1990) and Van Andel et al. (1986), who favour abandonment of agricultural terracing as a cause of accelerated erosion and alluvial deposition during the mid – late Holocene. One of Vita-Finzi’s arguments is the younger fill was deposited after the period of maximum disturbance of the environment and continued long after humans stopped disturbing the environment. However later dating on alluvial activity in the valleys of Greece indicate alluvial deposition extended back into the Classical and Bronze Ages (Davidson 1980; Wagstaff 1981; Pope and Van Andel 1984; Demitrack 1986; Van Andel et al. 1986; Chester and James 1991; Zangger 1992a; Runnels 1995b).

According to Zangger (1992b) both the Thessaly and the southern Argolid show long intervals of landscape stability during the Pleistocene to Holocene transition. This is despite the dramatic climatic changes occurring at the time. Zangger (1992b) appears to discount the work of Demitrack (1986), who recognised alluvial aggradation
Figure 2.11 Suspended sediment yield in the mountains of various climatic-vegetation zones showing the relative importance of natural and anthropogenic components (from Macklin et al. 1995, after Dedkov and Moszherim 1992).

Figure 2.12 Average rainfall and the distribution of glacial features and sediments in Greece from Woodward et al. after Osbourne (1987) and Denton and Hughes (1981).
between 14,000 and 10,000 years B.P (Mikrothithos alluvium), which is similar in age to the Syndendron alluvium of this study (see chapter 5). Van Andel et al. (1990) show that the Argive plain and the southern Agrolid indicate the global climatic changes of the last glacial-Holocene did not provide any significant alluvial deposition so typical of European valleys.

The late-glacial maximum, represented by the Bolling-Allerod warming, has been associated with high CH₄ levels indicating boreal vegetation and associated wetlands (Chappellaz et al. 1993). However, this seems not to be supported in northwestern Greece by pollen cores from Lake Gramousti, which suggest a period of increased temperate tree cover at 13.2-11.2 cal kyr BP (approx calibrated age), which is associated with the Younger Dryas period of drier cooler climate as shown in Figures 2.13 - 216 (Fairbanks 1989; Mithen 2003). However, the author has made only approximate radiocarbon calibrations, as the dates are listed in the paper as un-calibrated.

Jung et al. (2004) indicate the modern-day arid climate of NE Africa developed at about 3.8 kyr BP following a progressive drying of the climate during the early Holocene. They indicate arid periods at 8.5 kyr BP and then at 6 - 3.8 kyr BP, when the modern climatic conditions developed. In western Tibet Van Campo and Gasse (1993) indicated two arid periods at 7.7 and 4.3 kyr BP. While the period 7.5 – 6 kyr shows higher lake levels, other data indicate that the wetter conditions probably extended till about 5 kyr BP. Both these data sets indicate the early Holocene (>5 kyr BP) was wetter than the later Holocene. Recent sediment cores from the Adriatic and lakes in Italy indicate a wetter climate at 9.0 – 6.8 kyr BP (Aristegui et al. 2000; Kallel et al. 2000). This is supported by Huntley and Prentice (1993), who indicate that sites near the Mediterranean were wetter than present in the early and middle Holocene. However, Roberts and Wright (1993) in their detailed review of pollen and lake-level data indicate northern Greece was generally slightly drier at 9 kyr and slightly wetter at 6 kyr BP than today.

The Dead Sea is a terminal lake of one of the largest hydrological systems in the Levant. It acts as a large rain gauge for the region and thus variations in its level indicate climatic variations in the region. Enzel et al. (2003) identified a remarkably
close association between climatic changes in the Levant and culture shifts. The data of water levels indicate drier times after ca 4 kyr BP with a more moist early Holocene with the exception of low lake levels (drier climate) between ca 5.5 – 6.5 and ca 9 kyr BP (Enzel et al. 2003). Given the limitations of dating this gives a remarkably similar trend to those of Tibet and NE Africa (Van Campo and Francosie 1993 {Street-Perrott, 1990 #274}).

Wick et al. (2003) provide data from eastern Anatolia, Turkey, that indicate the late glacial period was cold and dry, with steppe vegetation and saline lake water. They indicate that during the Younger Dryas stadial the lake level dropped dramatically, and the vegetation turned to a semi-desert. The arrival of the Holocene saw a marked increase in moisture, as shown by partial replacement of Artemisia -chenopod steppes by grass steppe and pistachio scrub (Wick et al. 2003). There is a delay of about 3,000 years in the expansion of deciduous oak woodlands in the early Holocene and frequent steppe-fires indicate dry spring and summer weather. At 8,200 yr BP, a shift to more moist conditions saw steppe-forests dominated by Quercus advance to their maximum extension at about 6,200 yr BP. Wick et al. (2003) indicate there were optimum climatic conditions with low water salinity and high lake levels between 6,200 and 4,000 years BP in eastern Anatolia. However, after 4,000 years BP, aridity increased again and the modern climatic situation was established, as also shown in western Tibet, NE Africa and the Levant (Street-Perrott and Roberts 1983; Van Campo and Francosie 1993; Enzel et al. 2003). Human impact in the catchment of Lake Van started at about 3,800 years BP and was intensified during the last 600 years.

Goudie (1987) presents data for the climatic change at the Pleistocene – Holocene boundary (see Figures 2.13 and 2.14). These indicate that while the de-glaciation commenced at 14 kyr BP the most dramatic changes occurred at 12-10 kyr BP. These figures also suggest the climate was cool and dry in the glacial period but became warmer and moister in the postglacial period. During this period the probable vegetation in Grevena would have progressively changed from one of characteristic steppe-like and arid to a deciduous mixed oak forest (Goudie 1987). The mean air temperature increased in central Europe by approximately 6°C from glacial to
postglacial period (Flint 1971). However, this change may have been greater in the mountain regions (Goudie 1987).

Data on beetle populations in Britain supports the dramatic climatic fluctuations at the close of the last glaciation (Atkinson et al. 1987). They support the warming during the Allerod component of the late glacial climatic optimum after about 13 kyr BP before a dramatic deterioration to the full glacial conditions of the Younger Dryas period between 11 and 10 kyr BP. The Holocene interglacial period then begins dramatically after 10 kyr BP (see Figures 2.12 – 2.16).

This brief review of both late glacial and Holocene climate records is extremely useful in the context of the current study. Without such information it is more difficult to separate and assess the likely impacts of man vs climatic change when interpreting the sedimentary record over the last 15,000 years in Grevena.

**Causes of loss of tree cover**

A continuous vegetative cover is extremely important for the protection of the soil. A vegetative canopy intercepts rainfall and prevents the erosive effects of direct raindrop impact on bare soil (Hillel 1991). Beneath a continuous vegetative cover, leaf litters and root mats from rough surfaces obstructing runoff and acting as natural sponges which enhance infiltration. This results in reduced runoff and increased moisture storage for plant growth (Hillel 1998). Dense woody vegetation can also hinder animal traffic reducing the development of tracks and ruts that expedite water flow. The root systems of trees and other plants bind and hold soil to steep slopes that may otherwise be unstable (Hillel 1991). These root systems may also hinder rill formation and sheet erosion. Macklin et al. (1995) indicate there is a dramatic increase in erosion as vegetation cover drops below approximately 70% in the Mediterranean environment.

Wertime (1983b; 1983a) suggests that man the pyro-technologist has been possibly more devastating than man the settler and terrace maker in erasing Mediterranean trees. The need for iron tools and kilning of lime for cisterns would have driven demand for firewood. He indicates the industrial use of fire goes back to about 20,000 B.P. Wertime identifies four separate uses of fire for cooking of stones or
Figure 2.13  Paleo-climatic curves for the Last Glacial in the Near East and Western Europe, based on pollen analysis (cited in Goudie 1987 after Leroi-Gourhan, 1974). The inter-stadial names are for Western Europe while in the right-hand column certain names of local cultural phases are given.

Figure 2.14  Two different temperature records for the Holocene, giving two different date for the Holocene temperature “optimum”, (a) the oxygen isotopic curve for the Dome Ice-Core, Antartica (cited by Goudie 1987 after Lorian et al 1979), and (b) the oxygen isotope curve for a lake in Sweden (cited in Goudie 1987 after Morner and Wallin 1977).
Figure 2.15 Pale-o-climatic curves for the last 20,000 years based on oxygen isotope data based on ice cores from Greenland (Mithen, 2003).

Figure 2.16 The average temperature curve for Britain for the glacial maximum to early Holocene, as assessed from beetle remains (in Wilson et al. 2000 after Atkinson et al 1987)
Figure 2.17 Fluctuations of glaciers throughout the globe during the Holocene (after Rothlisberger 1986 cited in Grove 1988).
clay. They relate to firing of figurines in hearths, fire-drying of iron ochre for cosmetics, fire quarrying of siliceous stone for useful cores to flake, and thermal alteration of flints, jaspers and chalcedonies and cherts to afford cleaner breaks. Wertime (1983b; 1983a) indicates that between 1200 and 900 BC the hillsides of Israel, Greece and Italy had a massive and enduring encroachment of man on the forests, partly driven by pyro-technological industries.

Goudie (1993) has summarised studies on the use of fire by man and concludes that while the deliberate use of fire by man extends to 1.4 Ma BP (Gowelett et al. 1981) Palaeolithic man was a master of its use. He also suggest the “Palaeolithic might more accurately be termed the ‘Paleoxylic’ or ‘Old Wood Age’”. This is because Palaeolithic man used wood not only for fire but building, ladders, pigments (charcoal) and digging sticks.

Forbes and Koster (1976) remind us that 1,000 donkey loads of juniper wood are required for one limekiln burn. Lime plastered buildings have been favoured in the Mediterranean since the Neolithic. With the wave of cistern building and cement-brick construction after the 3rd century BC create heavy demands on forest resources (Wertime 1983b). Charcoal was also needed for industrial hearths, kilns and furnaces. Wertime (1983b) suggest the shift from extremely energy-inefficient copper age to the energy-efficient Iron Age was partly driven by firewood-resource demands.

Thus although a thorough examination of human archaeological history will be critical to the interpretations in this study, a knowledge of the history of fire use is also critical as shown above and by Chester (1991). Fire appears to be one of the key erosion producing anthropogenic activities in the Grevena environment.

**Seismicity impacts on stream behaviour in the region**

Tectonic activity in the catchments is another factor that may greatly affect erosion and deposition rates. Relative uplift and subsidence movements may result in a situation where erosion from uplifted areas leads to accumulation of thick sedimentary deposits in the subsiding areas. Also the shattering of rock along fault zones may lead to preferential erosion and transport to other parts of a catchment.
Lewin (1995) and Collier et al. discuss the impacts of tectonics on river behaviour in selected Greece basins but conclude in the mid to late Holocene anthropogenic or climatic influences appear to be the overriding causes of alluvial aggradation. While the tectonic processes controlling the magnitude, position and development of the basins (Collier et al. 1995). Collier et al. indicate the north-central Greece region is “seismically almost inactive” and that more arid climates of the late Holocene have seen incision in catchments unaffected by anthropogenic influences.

Karakaisis et al. (1998) indicate western Macedonia as an area of generally low seismicity. This is based on historical information and instrumental data. The Grevena 1995 earthquake exhibits the highest seismicity in a period of fifty years and is related to the graben structures of the area (Karakaisis et al. 1998). Karakaisis et al. also suggest the triggering of the 1995 earthquake may be related to the impoundment of the Polyfytos artificial lake. Macklin et al. (1995) indicate that most of Greece lies within a “very heavily exposed seismic zone”.

Chatzipetros et al. (1998) provide paleo-seismological evidence on the 1995 Grevena earthquake and revealed faulting at ca. 8.97, 36.7 and 72.5 kyr BP. The recurrence interval of faulting is thus about 30 kyr, which is very long, and thus verifies the ‘low seismicity’ status of the Kozani – Grevena region. The 1995 earthquake appears to be an out-of-sequence event, because the elapsed time since the last major event is only 9 kyr instead of 30 (Chatzipetros et al. 1998). This would support the idea the construction and filling of Lake Polyfytos may have been a trigger for the 1995 earthquake.

This review of relevant seismicity data indicates the role of tectonic events in the late Pleistocene and Holocene are likely to be very minor in comparison with the roles of climatic change and human activities in the Grevana landscape.

Summary
It appears that the Nomos of Grevena has had a relatively active archaeological record in the period since the Upper Palaeolithic period with low numbers of sites only in the Mesolithic, Archaic and the Early to Middle Byzantine periods (Wilkie et al. 1990; Wilkie and Savina 1992; Wilkie 1993; Wilkie 1995; Wilkie and Savina 1997).
CHAPTER 3 Methods and Materials

Field work and sampling
Field work and sampling were undertaken during June – October 2001. Key sections were described using stratigraphic principles, and some sections from Doyle (1990) were re-examined and charcoal samples taken for dating. Approximately 110 soil and sediment samples were taken from key sections for laboratory analysis.

Soil profile descriptions and soil mapping undertaken by the author in summer field seasons in Grevena in 1988, 1989, 1992 and 1997 were reviewed and where appropriate re-interpreted. Focus was placed on sections that had been dated or contained identifiable potsherds to allow the development of a sedimentation and erosion history.

In 2001 thirty-two samples of charcoal were collected from key stratigraphic layers for dating by the radiocarbon method. The charcoal was extracted from the sections by holding a plastic tray up against the section and extracting fragments of charcoal with tweezers and a small knife. The samples were then sorted on the tray to separate charcoal from soil aggregates and to remove visible roots. Of the 32 samples, twenty-six were selected for radiocarbon dating at the University of Waikato in Hamilton, New Zealand (www.radiocarbondating.com).

Definition of field terms used
The tabulated descriptions in the text use the following abbreviations. Soil structural development (pedality) is graded from 0 to 3; where 0 = no soil structure, i.e., the soil is massive (MA), or single grained (SG), 1 = weak, 2 = moderate and 3 = strong soil structural development (McDonald et al. 1990). The development of moderate to strong structure suggests the materials have undergone pedogenic development; typically soil organic matter incorporation, weathering and production of iron oxides and/or multiple wetting-drying cycles of the soil materials. Strong pedality is usually associated with stable soil forming conditions; however, soil creep or shallow landslides may move soil while retaining its pedality (see Plate 3.1). The types of structural aggregate present are polyhedral shape (PO), angular block (AB), subangular block shaped (SB) and prismatic (PR) (McDonald et al. 1990). The presence
of roots, tubular pores, earthworm castings, accumulation of humus, structural
development and initial leaching of carbonates indicates that soil development has
occurred in recent sediment. Soil colours both moist and dry were recorded using
Munsell soil colour charts (Kollmorgan Instruments 1994).

Reaction to 10% HCl reported in field morphology tables is undertaken as follows:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>%CaCO₃</th>
<th>Auditory Effects</th>
<th>Visual Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Non-calcareous</td>
<td>0.1</td>
<td>Inaudible</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Very slightly calcareous</td>
<td>0.5</td>
<td>Faintly audible</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Slightly calcareous</td>
<td>1.0</td>
<td>Faintly to moderately audible</td>
<td>Slightly effervescent, just visible slightly more visible</td>
</tr>
<tr>
<td>3</td>
<td>Calcareous</td>
<td>5.0</td>
<td>Easily audible</td>
<td>Mod. effervescent, easily visible bubbles to 3 mm diameter</td>
</tr>
<tr>
<td>4</td>
<td>Very calcareous</td>
<td>10.0</td>
<td>Easily audible</td>
<td>Strongly effervescent easily visible bubbles up to 7 mm diameter over most of the surface</td>
</tr>
</tbody>
</table>

The types of alluvial and slope deposits are categorised as follows:-

CD    Channelised coarse alluvial deposits (rounded, well sorted, clast-supported, stratified, and often imbricated gravels or stones).
OB    Finer textured, stratified, well sorted, rounded sediments termed over-bank deposits.
IN    Stream incision – indicated by an erosional break in the section.
SO    Soil profile development (weathering, structural development, and accumulation of organic matter occur.
CO    Colluvial slope deposits transported by creep and gravity.
SW    Slope wash deposits exhibiting features of water transported sediment such as bedding, rounding, and sorting.
SL    Stone-line, semi continuous line of coarse fragments forming a stratigraphic break in the soil profile. These features indicate an erosional break commonly followed by further finer-textured deposit.
DF    Debris flow deposit. These materials are poorly sorted, lack internal stratification, and contain typically more angular coarse fragments.
LD    Levee-type deposits. Sandy deposits forming on the margin of a streambed.
TSO   Intact transported pieces of soil.

Other abbreviations include;

Ma Million years
kyr Thousand years
AMS Accelerator mass spectrometry
asl/ASL Elevation above mean sea level
BP Before present
Topographic maps

A Greek Forest Service 1:20,000 scale topographic map was digitized and geo-referenced to provide a tool for site analysis and interpretation (see Figure 1.3). A three-dimensional topographic model or TIN was produced using ArcView software (Figure 1.4). All sites were geo-referenced for display and topographic analysis. The low-contour resolution of 20 m meant little analytical use was made of this information. However, the map does provide a good topographic overview of the catchment, and all sites are displayed on the map (see Figure 1.3).

Repeated applications were made to acquire detailed topographic maps at a scale of 1:5,000 though I.G.M.E. and by direct approach to the Greek Military Mapping Division (via my Greek teacher Mr Costantinous Adamopolis). The Greek military restricts foreign access to detailed topographic maps and aerial photographs. Fortunately on a second trip to Greece Mr Costantinous Adamopolis was able to get the required maps, and censored copies were received by the author in late January 2004. They have been used to display sites and aid in site interpretations. Some important parts of the maps have been removed; one would guess these are because they display important government installations. The key parts of the maps were computer scanned and sites marked to show the geomorphic relationships at each site. Had these maps arrived earlier (first applied to get them in late 2001) it would have been possible to have them digitized and to undertake more detailed GIS analysis.
Despite this they have proved extremely useful in the final interpretations and write-up of this study.

**Satellite imagery**

The Grevena Archaeological Project purchased a 1987 satellite scene from SPOT Image Corporation in Toulouse, France in 1994. This image covered the entire Nomos of Grevena. The aim was to use the image to examine soil erosion and geological relationships in the catchment. The image was geo-referenced and displayed using the *Imagine* software with the assistance of Ms Rachel Barrett (University of Tasmania, Burnie). The image was not classified due to its poor resolution and has simply been used for display purposes in this study (see Figure 1.5). Further analysis on a regional basis may provide some useful data on erosion – lithology relationships and erosion – topography relationships. Classification of the image was attempted in order to show bare ground, agricultural land, maquis and forest. However, given the small size of the catchment and low-resolution of the image the classification proved to be unreliable and so has not been presented here.

**Aerial photograph analysis**

The Grevena Archaeological Project obtained a photocopied set of 1:15,000 black and white aerial photographs taken in 1966 of the Leipsokouki catchment. These were examined as stereo pairs using a Sokkia 3 times magnifying stereoscope. This was to aid site interpretations and geomorphic analysis. Doyle had used these aerial photographs to produce a soil map of the catchment (Doyle 1990). The photographs aided interpretation of landforms, allowed examination of source areas of debris flows and examination of active faulting. More recent and higher-resolution photographs would have been of enormous benefit but were not available despite applications via the I.G.M.E. geologist for Grevena, Dr Anne Rassios, on my behalf. Dr Rassios informs me that in the year of the Athens Olympics it is finally getting easier for foreigners to obtain basic information to aid soil, geological, geomorphic and archaeological research in Greece.

**Wet chemistry of soils and sediments**

Laboratory analysis of samples was restricted to a few key parameters aimed at extending earlier analytical work by Doyle (1990). Reaction to 10% dilute
hydrochloric acid to estimate calcium carbonate content and soil pH were seen as important indicators of both the leaching environment and soil disturbance, and these two tests were performed on all samples. Organic carbon content was measured on all samples to help confirm the presence of buried topsoils identified on field criteria (earthworms, colour, structure, roots, mottling feature etc).

Soil pH and electrical conductivity were determined in duplicate on air-dried samples using the methods outlined in Rayment and Higginson (1992). The pH was measured using a Hanna HI 9025C pH meter with two-point buffer calibration on a 1:5 soil to distilled water ratio. Electrical conductivity was measured using a Hanna HI 933100 dual point calibration and temperature-correcting electrical conductivity meter.

Organic carbon analysis was undertaken in duplicate using wet oxidation in concentrated sulphuric acid in the presence of sodium dichromate. The samples were compared with similarly treated sucrose standards on a Perkin-Elmer Sigma 20 spectrophotometer using the method of Rayment and Higginson (1992).

**Whole soil mineralogy by X-ray diffraction**

Whole soil mineralogy was determined on randomly oriented samples on an automated Philips X-ray diffractometer with Cu radiation and a graphite monochromator. Semi-quantitative analysis by peak height was used to calculate mineral abundances (Wooley and Botrill 2003). X-ray diffraction relies on the "reflection" of an X-ray beam from a stack of parallel equidistant atomic planes, controlled by mineral type. The diffracted X-ray beam is given by Bragg's law, where \( n\lambda = 2d \sin\theta \) (McLaren and Cameron 1996). The X-ray wavelength \( \lambda \) is given by the radiation emitted from the X-ray tube (Cu, Co, Cr or Mo), \( \theta \) is angle of reflection, and \( d \) is the mineral lattice spacing. Every mineral shows a characteristic set of \( d \)-spacings, which yields a characteristic diffraction pattern and allows identification. Mineral determinations were undertaken using \( d \)-spacings with the peak heights being used to provide semi-quantitative percentages of each mineral present to be determined. The accuracy of the measurements is in the order of +/-5% (Wooley and Botrill 2003).
In samples with clay minerals a measured XRD peak width at half-peak height and a determination of appropriate correction factors from a calibration series (for mixtures of clays of different crystallinities) was undertaken (Wooley and Botrill 2003). The peak height was then multiplied by the selected factor. For other minerals, the peak height was multiplied by a standard mineral-specific correction factor, although this correction factor could be varied if the crystallinity was clearly abnormal. With some difficult samples, known weights of the particular sample and a mineral/compound not found in the sample for which there are calibration data may be combined and X-rayed for cross-checking purposes (Wooley and Botrill 2003).

**Whole soil elemental analysis using X-ray fluorescence**

Major elements in the whole soil samples (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K and P) were determined with a Philips PW 1480 X-ray Spectrometer using lithium borate fusion discs located in the School of Earth Science, University of Tasmania. The principle is based on a primary X-ray excitation source from an X-ray tube or a radioactive source striking a sample (Pecsok et al. 1976). The X-ray can either be absorbed by the atom or scattered through the material. The process in which an X-ray is absorbed by the atom by transferring all of its energy to an innermost electron is called the "photoelectric effect." During this process, if the primary X-ray had sufficient energy, electrons are ejected from the inner shells, creating vacancies. These vacancies present an unstable condition for the atom. As the atom returns to its stable condition, electrons from the outer shells are transferred to the inner shells and in the process give off a characteristic X-ray whose energy is the difference between the two binding energies of the corresponding shells (Pecsok et al. 1976). Because each element has a unique set of energy levels, each element produces X-rays at a unique set of energies, allowing one to non-destructively measure the elemental composition of a sample. The process of emissions of characteristic X-rays is called "X-ray Fluorescence," or XRF. A typical X-ray spectrum from an irradiated sample will display multiple peaks of different intensities (Pecsok et al. 1976).

**Radiocarbon dating background**

The radiocarbon method is based on the rate of decay of the radioactive or unstable carbon isotope $^{14}$C. Plants and animals all utilise carbon in biological food chains and take-up $^{14}$C during their lifetimes. There is an equilibrium between with amount of
$^{14}$C and non-radioactive carbon in these organisms as they respire. However, when the plant or animal dies, they cease the metabolic function of carbon uptake; there is no replenishment of radioactive carbon, only decay. Libby, Anderson and Arnold (1949) first discovered this decay and determined that it occurs at a constant rate. They found that after 5568 years, half the $^{14}$C in the original sample would have decayed (Figure 3.1). The half-life ($t_{1/2}$) is the name given to this value, which Libby measured at 5568±30 years (the Libby half-life). By measuring the $^{14}$C concentration or residual radioactivity of a sample whose age is not known, it is possible to obtain the count rate or number of decay events per gram of carbon. By comparing this with modern levels of and using the measured half-life it is possible to calculate the date of death of the sample. This means the sample must lie in a counter for several weeks to get a reliable measure from the remaining radioactive carbon (Hogg 2003).

For small samples radiocarbon dating by accelerator mass spectrometry (AMS) is the preferred method as it counts the atoms of the different carbon isotopes directly. It is thus more sensitive and provides better age determinations than traditional decay counting (Hogg 2003).

**Radiocarbon dating of samples at Waikato University**

The charcoal samples received standard pre-treatment that involves acid wash to remove carbonates and fulvic acids, NaOH wash to remove humic materials, followed by an acid wash (Petchey 2001).

The Waikato laboratory determines $^{14}$C activity through the measurement of beta particles. Samples are converted to benzene through hydrolysis of lithium carbide and catalytic trimerisation of acetylene (Hogg 2003). The residual radiocarbon activity is measured using a LKB/WALLAC 1220 "Quantulus" Liquid Scintillation (LS) spectrometer (Hogg 2003). The instruments design allows for optimal counting conditions and data validation as it has dense shielding, so there is reduced background radiation. All of this allows for both older and smaller samples to be dated more accurately (Hogg 2003).

Calibration of the conventional radiocarbon ages (Libby age) to calendar years was undertaken using a computer program available on the web at
Plate 3.1 Shallow soil slip which can result in very low soil profile disturbance. The result being pedogenic deposits with inherited soil characteristics.

Figure 3.1 Decay curve for $^{14}$C showing the activity at one half-life (t/2).
http://www.rlaha.ox.ac.uk/orau/06_ind.htm (see Stuiver et al. 1998). Appendix 1 has a table showing the % modern carbon, the conventional date and the calibrated date in years BP for all samples based on these corrections. The 95% probability calibrated ages have been used for discussion in the thesis as they provide the best estimate of the correct age range of the sample in years before 1950. The conventional (Libby) dates and the dC13 values are provided in Appendix 1 should the reader wish to undertake further or more recent calibrations.

**Microscopy**

Samples were examined and photographed with a variable Pentax 5 - 15 times magnifying lens mounted on an adjustable frame. A digital video camera was attached to the lens to allow viewing and photography of the specimen. The images of specimens were then converted to JPEG file format for display in text and diagrams. In addition all samples were examined using six times magnifying head-fitting lenses for pedogenic features such as earthworm channels, precipitate features (both calcareous and ferruginous), pedality, clay coatings, lithic fragments (size, shape, distribution), fine roots, slicken-sides and ped surface features e.g., mangans, ferrans, calcans etc.

**Scanning electron microscopy**

Strategic samples and materials were analysed using an Electric Scan ESEM2020 (environmental scanning electron microscope) in the Central Science Laboratory at the University of Tasmania. The instrument was used at a voltage of 15 Kv with spectra acquired in the “wet mode” at a chamber vacuum pressure of 5 Tor. The samples were not pre-treated to allow analysis of semi-quantitative elemental composition using the backscattering electron detection system (Danilatos 1993). The spectra were acquired using an Oxford Link Pentafet SATW energy dispersion spectrometer. This allowed identification on manganese, calcium carbonate and ferruginous coatings and nodules as well as clay minerals and lithic fragments in some samples (David Steele, pers comm.).
CHAPTER 4 Geological overview and description of key soils of drainage divide

Introduction
This chapter provides background on the catchment geology and geomorphology followed by details on the soils of the catchment divide. The bedrock geology, the Mersina surface (a large elevated plain ca. 620 - 630 m asl) and the Plio-Pleistocene sediments are discussed. The deep and highly developed soils of the catchment divide are also discussed (>720 Ka). The later sections of this chapter provide descriptions and analytical data on some key soils and parent materials.

Soils in the catchment
Studies of the modern soil profiles and their general chemical fertility have been conducted throughout the Nomos of Grevena by the Greek Institute of Soil Science and as part of the Grevena Archaeological Project (Spiropoulou et al. 1983a; Spiropoulou et al. 1983b; Oikonomou et al. 1985; Spiropoulou et al. 1985; Oikonomou et al. 1988; Doyle 1990). These surveys indicate the modern soils generally have good chemical and physical fertility, a fact born out in this study. The soils are typically neutral to slightly alkaline with high base status and moderate levels of available phosphorus. Many of the more extensive areas of alluvial soils, such as those along the Venitikos and Haliokmon rivers, have been developed for irrigated agriculture and produce corn, tobacco and sunflower seeds.

Many of the soils in the mid catchment have highly calcareous subsoils. They typically do not develop distinct B horizons and may be considered rendzinas. Such soils classify as calcareous varieties of mollisols and vertisols in the US Soil Taxonomy system. The soils in the lower catchment, especially those on slopes, are quite gravelly and loose and thus would be prone to droughtiness. Doyle (1990) has provided a map of the soil types in the valley and has noted that recent soil erosion has led to the formation of many recent soils or entisols and inceptisols in addition to bedrock exposed in gullies and the valley floor.

The most strongly developed profiles occur on the catchment margins. Some of these are paleosols, many of which do not develop typical “colour B horizons” but do
develop significant calcium carbonate nodules and in places calcrete. This is because of the prevalence of reactive clays that result in shrinking-swelling cycles and thus soil profile churning which partly or wholly destroys pedogenic horizonation.

In the catchment, all the villages are located on the drainage divide or Mersina surface. So are the villages in many neighbouring catchments. The catchment does not have significant areas of alluvial soils in the valley floor, and thus the most extensive areas of good arable land are on the upper plateaux and valley heads and high surfaces.

Geomorphology of the valley

The Leipsokouki valley is narrow, elongate and deeply incised, up to 120 m in places. Many short tributaries descend from the drainage divides and transport large amounts of sediment to the valley floor, forming alluvial fans and terraces. Many of the tributaries have evolved into gullies due to erosion during the Holocene. In the valley bottom late Pleistocene to Holocene alluvium has accumulated as fan and terrace deposits.

Hillslopes

Hillslopes occur throughout the catchment. Much of the mid and lower catchment topography is a mixture of steep hillslopes (15⁰-30⁰+) separated by gently sloping surfaces (5-15⁰), giving a stepped landscape form. Hill slopes of varied lengths separate these gently sloping surfaces; some are steep (>15⁰) and are dissected by erosion. The upper catchment area has a steeper topography dominated by hill slopes. Flattish areas are restricted to ridge top, straths/benches, gently sloping fans in the valley and gully floors. Gullying has produced many very steep slopes, which dissect fans, terraces and hill slopes throughout the catchment in a somewhat chaotic manner.

Mersina surface

In the lower catchment the drainage divide is formed by a broad gently undulating upper aggradation surface, named the “Mersina Surface” by Doyle (1990). The upper cover beds on this surface cap the ridge tops that gradually increase in elevation up to 990 m asl in the upper catchment drainage divide. The surface is underlain by 120 m of Plio-Pleistocene sediments, which are described below.
Strath or benches cut in the valley side

At least two lower erosion surfaces are clearly visible as benches cut into the valley side downstream of Mega Sirini. Downstream of Mega Sirini the drainage divide is formed by the Mersina surface, which is a broad plain developed on the top of the Plio-Pleistocene sediments. In the mid catchment the bedrock changes from the unconsolidated Plio-Pleistocene sediments to more competent inter-beded mudstones, siltstones and sandstones. Erosion and deposition in the mid catchment masks the presence of the strath surface. In the upper catchment the strath terraces, although probably present, are hardly apparent and "moderately dissected hill country" is a more apt description of the landscape.

Modern alluvium

Very recent alluvium, with incipient topsoil development, has accumulated on the valley floor. This alluvial material forms fans and terraces at heights typically ranging from 1 - 2 m to 3 - 4 m above the modern streambed. These materials were named the Leipsokouki alluvium by Doyle (1990).

Holocene alluvium

Thicker alluvium, which typically forms fans, has been deposited in some parts of the valley floor. These materials commonly have gently sloping surfaces (1-5°) and they occur at heights of 6 - 7 m, 8 - 10 and 12 - 14 m above the modern streambed. This alluvial material has been named the Sirini alluvium by Doyle (1990). Several topsoils have formed during the deposition of this alluvium and are buried within it. Modern topsoil has formed on the alluvial surface. Creep, colluvial movement and in some cases short-distance slope wash appear to have transported soil-like sediment onto the stratified alluvium. Thus in some situations soils have or are forming from a partly pedogenic material. Thus great care needs to be taken in interpretation of such soil material, as indicating a period of stable landscape. Care also needs to be applied to interpretation of soil-time relationships.

Late Pleistocene – Holocene alluvium

A prominent gently to moderately sloping (3-6°) alluvium has formed a series of fans on the valley floor. They typically occur at a height of 20-30 m above the valley floor. This alluvial material has been named the Syndendron alluvium by Doyle (1990). There is an alluvial soil that forms on this surface, which is buried by soil-colluvium. This fan alluvium is most prominent at Tsifliki and below Paleokastro but is also present in the lower catchment as a terrace deposit (refer to Chapter 5).
**General description of the bedrock geology**

In the Leipsokouki catchment two types of bedrock occur. These are the Tertiary marine sedimentary rocks in the upper two-thirds of the catchment and Plio-Pleistocene sediments. The upper beds of the Plio-Pleistocene sediments are dominated by fluviatile sands that cap and in places are inset into a series of loess deposits, which contain paleosols (Doyle 1990). Rassios (2004b) has indicated these inset fluvial sediments contain mastodon fossils dated to ca. 200,000 yrs BP. The full Plio-Pleistocene sequence occurs in the lower half of the catchment while the upper loess beds and paleosols extend as cover bed across the catchment divide on the Tertiary strata which underlie the mid and upper catchment. These two lithological units, Tertiary and Plio-Pleistocene sediment, underlie most of the central Nomos (see Plates 4.1 and 4.2).

**Tertiary (Late Oligocene - Miocene) marine sediments (30 – 7 Ma BP)**

The Tertiary rocks are moderately consolidated, calcareous, inter-bedded marine mudstone and fine-grained sandstone. The proportion of sandstone to mudstone increases upstream.

The clay content of a typical mudstone is high (30%) and is predominantly less than 1 µm in size i.e., fine smectite clay (Doyle 1990). The finer beds typically contain 46% silt, most of which is fine silt and has 24% fine sand (see Doyle 1990). The fine texture means they are slowly permeable and are dependent on fracture porosity for groundwater storage. The mudstones have a distinctive blue-grey colour and a mixed clay mineralogy that is dominated by expanding 2:1 lattice clays. Smectite content is 40%, chlorite 28%, hydroxy inter-layered vermiculite 22% and mica 10% (see Doyle 1990). The mudstones contain up to 36% calcium carbonate.

The sandstone components typically contain 72% fine sand, 26% silt and only 2% clay (see Doyle 1990). Their sandy texture means they have generally higher permeability than the mudstones. The sandstones are light grey in colour and very micaceous. Quartz and feldspar dominate the sand mineralogy. The minor clay fraction (2%) has a mineralogy dominated by mica (51%, illite) with even amounts of chlorite (26%) and smectite (23%) (see Doyle 1990). The sandstones contain much less calcium carbonate (18%) than the mudstones (36%).

The Tertiary sediments dip gently (80-100) to the north, i.e. into the valley floor on its true right-hand side. This dip may have implications for water seepage and springs in
Plate 4.1

Fault displacement in Miocene marine sediments near village of Rodia, Grevena. Suggests tectonic activity in last 5 million years.

Plate 4.2

Miocene marine sediments capped by the Plio-Pleistocene cover beds (white arrow). Photograph is taken in head of extremely large gully in the mid catchment. Location is 3.2 Km east of Syndendron and 1.5 km WSW of Mega Sirini (see Figure 4.6 marked at P60)
Figure 4.1 Geological maps (above and below) of the study area (marked by dashed lines). Plio-Pleistocene sediments (yellow colour with pattern), Tertiary sedimentary rocks (salmon colour) and Quaternary alluvial deposits (blue)
the area. There is also evidence of post-Miocene faulting at Rodia in the upper catchment (Plate 4.1).

**Pliocene-Pleistocene (7 Ma – 10 Ka)**

Up to 120 m of Plio-Pleistocene sediments cap the Tertiary rocks in the Leipsokouki catchment and much of the rest of the eastern central part of the Nomos of Grevena. They can usefully be divided into the lower more gravelly section and the upper finer (silty) textured section. The upper section is referred to here as “Upper Plio-Pleistocene cover beds” or in short the “cover beds” (see Plate 4.2). This distinction is useful as many of the layers in the upper cover beds appear to be silty loess and paleosols (see Plates 4.3, 4.5 and 4.7). This means they are deposited as a mantle on some of the hill slopes and ridge tops in the mid and upper catchment areas i.e., at elevations higher then the Pleistocene Mersina surface.

*Upper Plio-Pleistocene cover beds*

In the upper part of the Plio-Pleistocene sequence, the more gravelly lower section gives way to an upward increase in inter-bedded coarse and fine sands, which in turn grade upward into calcareous silts and clays with intervening paleosols. This upper set of sediments is interpreted as channel deposits grading to overbank deposits, loess beds and paleosols (see Plates 4.3, 4.5, 4.7 and Figure 4.3).

*Lower Plio-Pleistocene gravels*

The clast-supported, rounded, beds of gravel that are dominant in the lower half of the Plio-Pleistocene sediments were assessed using a pebble count of the various lithologies of which they are comprised. This was undertaken at the base of a section in the lower catchment. The lithologies in this section revealed that most clasts (59%) are igneous rocks, namely gabbro, diabase and some diorite, with common highly weathered ultramafics, peridotites and pyroxenites (Savina, written communication). Limestone (27%) and indurated sandstone (10%) are common, with minor chert (2%), quartz (1%) and amphibolite (1%) (Savina, written communication). Lithologies such as diabase and chert are commonly used for stone tool manufacture, while highly weathered ultramafics could provide an excellent source of ochre and iron oxide.

**Measured section in Plio-Pleistocene sequence**

A stratigraphic section was measured from 55 m above the base of the Plio-Pleistocene section to the top of the section at the Mersina surface (latitude 40.098° and longitude 21.459°). The section was exposed during construction of the new Thessalonica to Igoumenitsa highway, starting 2 km northeast of Grevena at 510 m
and climbing up to the Mersina grain elevator at 625m (see Plates 4.3 - 4.5). The first 45 m of section is covered by slope deposits.

**Stop 1 - base of section is at 555 m asl and top of exposure at 565 m**
Mostly rounded gravels with cross bedding in finer gravels and sands toward top of section. Three distinct paleosols as evidenced by distinct large carbonate nodules in calcic horizons below dark, fine, silty clay textured soil profile. Truncated remains of a fourth paleosol occurs near the base of section 5-6 m above the road level. At this level calcium carbonate nodules can be seen in part of the soil. The majority of carbonate nodules are 5-10 cm in dia. and contain highly crystalline dehydrated (cracked) interiors. The calcium carbonate development stages are indicated in Plate 4.5.

**Stop 2 - base of exposure at 565 m asl, top of exposure at 580 m asl.**
Rounded, clast-supported gravels were present at the base with some finer beds occurring in the lower half of the exposure. These alluvial deposits are capped by the first of five paleosols formed in fine silty sediment (loess or fine alluvium). The paleosol is only semi-continuous laterally and has hard 5-10 cm calcium carbonate nodules. A second paleosol occurs 2-3 m higher, and this is capped by a third thick (2.5 m) and prominent paleosol with a very dark brown upper profile and pale subsoil. A fourth and thinner (1m) paleosol lies above with the final fifth paleosol at the top of section. Cross-bedded sands lie below the fifth paleosol, some vein carbonate occurs above the sand beds. Also carbonate nodules were present at the base of the exposure. Black to very dark grey cross-bedded fine gravels cap paleosol 1 (mid section).

**Stop 3 - base of exposure 580 m asl, top of exposure 605 m asl.**
Cross-bedded, rounded gravels with black grit/sand occur at the base (ca. 4m thick). The first silty paleosol is dark reddish brown with a blocky structure and a pale subsoil with carbonate accumulation (2 m thick). The second silty paleosol directly overlies the first (ca. 2 m). Above are cross-bedded gravels with some sand lenses (4 m). A thick dark reddish brown paleosol composed of possibly two soils with a dark grey silty layer separating them (ca. 3m). These soils are overlain by 4 m of grey, cross-bedded, rounded gravels. Above lies a fourth paleosol layer similar to the third and 2-3 m thick. On the opposite side of the roadway the exposure shows multiple thinner paleosols (five, possibly six are evident).
**Stop 4 - base of exposure 605 m asl, top of exposure 615 m asl.**

Fine cross-bedded gravels (1 m) were present capped by 1 m of fine alluvium. Above lies a 2 m thick paleosol section with distinct calcic horizon and 4 – 6 cm dia. calcium carbonate nodules. Above this are two thinner paleosols in total measuring 2 m in thickness. Twenty meters along the section a fourth paleosol is visible with abundant calcium carbonate at the base (1 m). These soils are capped by cross-bedded sands of 2 m thickness. This is capped by further 2 m of finer alluvium and more cross-bedded gravels.

**Stop 5 - base of exposure 615 m, top of exposure 625 m on Mersina surface**

Cross-bedded gravels (2-3 m) at the base of exposure are capped by 2-3 m of fine textured alluvium/loess with a thick palesol and distinct calcic horizon developed above (1-2 m). This is capped by a 2 m thick paleosol with carbonate nodules. Above this are three thinner paleosols developed in silty textured loess like material (3 m thickness).

**Stop 6 - base of section 615 m, top of section 625 m (200 m W of stop 5)**

The same loess and paleosol material as Stop 5 but the section is topped with 3-4 m of reddish sands and fine gravelly alluvium. These reddish coarse sands and fine gravels have also been noted capping the Plio-Pleistocene sequence at 650 m at Mega Sirini and the neighbouring ridge of St. Dimitrios but at a slightly higher elevation. This suggests they may be associated with the commencement of re-incision of the Plio-Pleistocene sedimentary stack. Rassios (2004b) has indicated it is within these upper beds that 200 kyr BP mastodon bones have been discovered. The silty cover beds have been noted at higher elevation near Syndendron (850 m) and on the ridge above Tsifliki (850 m) perhaps indicating tectonic uplift as the cover beds are dipping east at 20° at site CDS1. The cover beds also appear to be displaced by fault movement at Section 7B of Doyle (1990) as shown in Plate 4.7. Alternatively they represent aeolian cover beds which, due to their mode of deposition, would be capable of mantling the upper slopes as well as forming part of the Plio-Pleistocene sediment column.

The Grevenetikos River lies at 510 m asl at its confluence with the Leipsokouki stream. The lower part of the Plio-Pleistocene section, from 510 – 565 m asl, is buried by slope deposits and modern soils. Where small exposures do occur they suggest indicate water-worn gravelly deposits prevail. The top of the section is 625 m asl making the entire exposure 115 m thick. In the 70 m of exposure that was surveyed approximately 20 paleosols were identified. Identification was based on
Plate 4.3 Upper loess and paleosol beds of the Plio-Pleistocene sediments. The Mersina surface is developed on top of the sediment pile. The upper beds are composed of loess, fine textured alluvium and calcareous paleosols. Note white bands of calcium carbonate nodules (arrows) in the base of the various paleosols (they are classified as Stage II+ calci horizons).

Plate 4.4 Lower gravelly beds of the Plio-Pleistocene sediments. The section is dominated by alluvial gravel beds with minor beds of silty sediment and paleosols (darker beds in upper part of photograph). The finer sediments represent either fine over-bank or loess deposits while the gravels represent channel deposits. Carbonate horizons below soils appear to be Stage III according to Birkeland 1999).
Stop 1  620 – 630 m asl.
Base - three clear paleosols with calcic horizons, possibly 4th at road level, all with 5-10 cm carbonate nodules (Stage III). Inter-bedded with rounded gravels, with X-bedding.

Stop 2  630 - 645 m asl.
Clast-supported gravels capped by series of paleosols - some with 5-10 cm carbonate nodules.

Stop 3  645 - 670 m asl.
Cross-bedded gravels and grits/sands at base. Inter-bedded paleosols and X-bedded gravels with some finer lenses.

Stop 4  670 - 680 m asl.
Fine cross-bedded gravels capped by series of paleosols and finer alluvium. Upper section X-bedded fine gravels.

Stop 5  680 - 690 m asl.
Cross-bedded gravels at base capped by finer alluvium and two thick paleosols. Top of section possibly loess and thinner paleosols.

Stop 6  685 - 690 m asl.
Cross-bedded reddish gravels cap finer loess-like layers – perhaps represents fluvial phase associated with re-incision.

Plate 4.5 Measured section in Plio-Pleistocene sediments, 2 km NE of Grevena township.
texture, soil colour and structure and presence of pedogenic calcium carbonate nodules in the subsoil horizons. Most of these soils have calcium carbonate morphology Stage II to Stage III based on the table presented in Birkeland (modified from a number of sources, Birkeland) and these carbonate stages have been marked on Plates 4.3 - 4.5. Nine paleosols appear to be calcium carbonate stage II or II+ and may represent 50 – 150 kyr of soil development each while 11 paleosols appear to be the Stage III. Those paleosols with stage III calcic horizons may represent 150 – 500 kyr of soil development each as suggested by Birkeland (1999). He and others used dated soil sequences from the Colorado Piedmont and southwestern state of the USA, which has similar climate to Grevena, to determine the rate of calcic horizon development rates (Gile 1989; Machette et al. 1989; Birkeland 1999). Given that approximately 11 of the paleosols are stage III and nine are stage II or II+ this would make the upper 70 m of section between 2.1 and 6.9 million years (Myr) in age. If only one-third the number of the calcic paleosols occurred in the buried lower 45 m of the section then the total age for the sequences could be between 2.4 Ma and 7.7 Myr. Given the entire section is dated as Pliocene (7 - 2 Ma) to Pleistocene (2 Myr – 0.1 kry) i.e., 7 Ma duration each calcic paleosol at Stage II represents about 120 kyr while each Stage III would represent approximately 360 Kyr. These figures seem to be in close agreement with the upper age ranges for the stage of calcic horizon development in Colorado (Birkeland 1999). Birkeland (1999) indicates stage IV calcic paleosols represents approximately twice the value of stage III, in this case about 700 kyr.

Doyle (1990) has suggested a Stage III+ to IV calcic paleosol at the base of Section 7A in Plio-Pleistocene cover beds on a 650 m high hilltop near Mega Sirini might be 2.48 million years BP based on the Matuyama - Gauss palaeomagnetic boundary shown in Figure 4.2 and Plate 4.6 (Bradley 1985). Another interpretation is the palaeomagnetic signals represent the Matuyama – Olduvai Event boundary at 1.67 Myr. This later date seems in accord with the age estimates on the paleosols that form at the site. There are three paleosols at stage II+ in the upper reversed part of the section and a stage III+ - IV paleosol at the base of the section, where the signal becomes normal. In combination these paleosols may represent a total of approximately 1.1 Myr (if II+ are taken as 180 kyr and a III-IV calcic is taken as 550 kyr). This would suggest the younger palaeomagnetic interpretation might be the right one, i.e., the base of section 7A is 1.67 Myr.
The Plio-Pleistocene gravels, which are rounded, clast-supported and cross-bedded and which include thinner inter-bedded sand and grit beds have been interpreted as braided stream deposits (Savina 1989). Given the very gravelly and sandy nature of much of the identifiable alluvial sediment it seems clear that large braided streams were transporting materials from the surrounding mountains into the central basin. It would also seem likely that, as in New Zealand, the USA and central Europe these braided streams acted as source areas for aeolian entrainment, i.e., for loess. The silty beds within the sequences lack distinctive fluvial features, such fine bedding, grading, lateral changes in sediment type etc and are likely to be loess beds. Doyle (1990) has shown these sediments to have a grain size in the loess range with 45% clay, 30% silt and 25% fine sand (see Figure 4.3). The I.G.M.E. geological map legend (1983) indicates the finer beds may be lacustrine deposits. However, the pedogenic features associated with the layers, namely calcic subsoil horizons, dark colouration in the upper profile and strong soil structure in the upper profile, would suggest a sub-aerial mode of deposition followed by pedogenic development. Also the fact that these beds cap ridgelines at elevations well above (850 m) the Mersina surface would support the notion they are aeolian.

Modern soils developing directly on the gravelly facies of the Plio-Pleistocene sediments have little or no initial carbonate because of leaching of the porous gravelly materials (Doyle 1990). High permeability means these gravelly soils are both more leached and also droughtier than soils on the loessial cover beds or the mudstones and sandstone strata. The ultramafic clasts in the gravels are strongly weathered and enhance both the development of clay in the interstitial soil matrix and they impart yellowish to reddish brown colour to the subsoils.

Soils of the catchment divide and stable components of valley sides
Characterisation of the soils and sediments on the catchment divide (watershed) is important as they may act as source areas for soils and sediment lower in the catchment. In the Leipsokouki valley the soils and sediments on the drainage divide have complex and deep stratigraphy (Plates 4.2, and 4.6 - 4.10). Some paleosols and also modern soils appear to be of considerable age as indicated by an abundance of hard, precipitated, carbonate nodules in stage III calcic horizons (Birkeland 1999). Some of these paleosols been shown to have reversed over normal palaeomagnetic
signals (either 0.73 – 1.67 Myr BP, or 0.73 - 2.38 Myr BP boundary as shown in Plate 4.6) (Berggen et al. 1985; Doyle 1990). These chronological data and stratigraphic position indicate that the soils forming on the catchment divide, at least in the mid and lower catchment, are derived from the younger components of the Plio-Pleistocene sediments. The measured Plio-Pleistocene section described above suggests silty loess beds and paleosols dominate the upper beds, while braided river gravels inter-bedded with loess derived paleosols dominate the lower part of the Plio – Pleistocene sequence.

Characterisation of the soils and materials, which form on the catchment divide, is important as erosion of them provides materials for colluvium and various slope deposits that make their way to the lower slopes. Thus their characterisation is important for the interpretation and understanding of all younger soil materials examined in the valley. Several examples of buried, well-developed soils on remnant components of the valley sides will also be presented along with examples of mature modern soils on the valley sides.

Several types of mature soil were observed on the catchment divide and adjacent slopes. They included:

i) Black silty-clay paleosols with hard nodular carbonate (stage III calcic horizon) capped by calcareous silty clays (loess beds), which are deposited and formed on the catchment divide, refer to sites CDS1 and CDS2 (see Plates 4.8, 4.9 and 4.10).

ii) Terra Rossa soils with reddish brown, strongly structured profiles and calcareous subsoils developed on parts of the catchment divide, refer to site CDS-Red (see Plate 4.13).

iii) Truncated and buried Pleistocene paleosols on the catchment divide and upper valley slopes, refer sites CDS3 and CDS4 (Figure 4.11 and Plates 4.14 - 4.17).

iv) Mature reddish-brown soils, some exhibiting 10-20 mm pedogenic carbonate nodules in growth position (stage II+ calcic horizon). These soils occur on the valley sides and in places are buried by colluvium, refer to sites C7, C10, P60 and CDS3 (Plates 4.18 - 4.21).
Figure 4.2  Paleomagnetic polarity timescale for the last 5 million years. Normal polarity periods are in black. Dates are based on K/Ar dates on lava flows using recent revisions of time constants for potassium-40 (cited in Bradley, 1985 after McDougall 1979 and Mankinen and Dalrymple 1979).

Figure 4.3  Particle size distribution curve for soil and loess beds in the upper Plio-Pleistocene sequence at Section 7A after Doyle 1990. Paleosols have finer texture (ZLC) while the loess layers have more fine sand (ZCL).
Plate 4.7. Section 7A from Doyle (1990) showing a fault displacement of the upper loess beds of the Plio-Pleistocene sequence, 1 km southwest of the village of Mega Sirini. There appears to be no clear surface expression of the fault scarp at the site nor nearby. Note also the darker layers (soils) have been dragged downward indicating the up-hill part of the section was uplifted, by at least the height of the section. Also note soil horizons dip into valley as occurs in CDS1 paleosol. These features indicate early Pleistocene faulting and tilting.

Plate 4.6. Shows section 7A from Doyle (1990) with palaeomagnetic data from Doyle (1990, see Appendix 3). Upper part of section is reversely magnetised and lowest part is normal. This may represent either the Matayama-Gauss Boundary at 2.38 Myr or the Matayama- Jalamaro event boundary at 1.67 Myr.
Introduction

The CDS1 soil section occurs on the catchment divide at an elevation of 720m on the road between Grevena and Syndendron (40.1135° N, 21.3874° E, see Plates 4.8 - 4.10 and Figure 4.4). A visually striking sloping paleosol can be seen in the road cut buried by up to 6m of pale olive calcareous fine sandy clay loam (Plate 4.8). Samples have been analysed of the black calcareous paleosol and the overlying sediments. The paleosol dips to the east at approximately 20 degrees. Below the paleosol lies a fine textured material with sub-rounded to sub-angular lithic fragments set in a silty clay loam matrix suggesting it is some form of slope wash. This overlies the Tertiary bedrock. Site CDS 2 is located 150 m SE along the ridgeline. This section has a strongly structured paleosol with light olive-brown colour occurring within loess beds (see Plate 4.10). This paleosol has strongly developed angular pedality and is inter-bedded with loess as indicated by Doyle 1990 (see Plate 4.10). This paleosols B horizon was sampled to allow comparison with colluvial soil-like materials at lower elevations. Doyle (1990) provided some particle size analysis of paleosols and inter-bedded silty clays at the hill top of St Dimitrios, near Mega Sirini (Plates 4.6 - 4.7 and Figure 4.3) and concluded they were loess beds and associated paleosols based on the lack of coarse fragments, the silty clay texture and the uniformity of the materials. Details of the field, and XRF and XRD properties of the CDS1 and CDS2 structured B2 horizon are included in the Tables 4.1 – 4.3 on the following pages.

Table 4.1  Field data for CDS1 and CDS2

<table>
<thead>
<tr>
<th>CDS1 Black calcareous paleosol</th>
<th>Depth (m)</th>
<th>Hor</th>
<th>Unit description</th>
<th>Field Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Soil Structure</th>
<th>React HCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>at -0.5</td>
<td>C</td>
<td></td>
<td>Upper loess overlying black calcareous soils</td>
<td>FSCL 5Y 6 3</td>
<td>5Y 6 3</td>
<td>5Y 8 2</td>
<td>0 MA</td>
<td>4</td>
</tr>
<tr>
<td>0-0.2</td>
<td>2A11</td>
<td></td>
<td>Topsoil of in situ black calcareous soil materials</td>
<td>ZLC+ 2.5Y 4 2</td>
<td>2.5Y 4 2</td>
<td>10YR 4 1</td>
<td>3 PO 5-10mm</td>
<td>3</td>
</tr>
<tr>
<td>at 0.4</td>
<td>2A12</td>
<td></td>
<td>Black calcareous soil materials</td>
<td>ZLC+ 2.5Y 4 2</td>
<td>2.5Y 4 2</td>
<td>2.5Y 4 1</td>
<td>2 PO 5-10mm</td>
<td>3</td>
</tr>
<tr>
<td>0.9-1.1</td>
<td>2Ck</td>
<td></td>
<td>Calcareous nodule layer</td>
<td>ZLC- 2.5Y 6 2</td>
<td>2.5Y 6 2</td>
<td>5Y 7 2</td>
<td>2 PO 2-10mm</td>
<td>4</td>
</tr>
<tr>
<td>1.1-1.3</td>
<td>3A</td>
<td></td>
<td>Dark layer below calcareous horizon</td>
<td>ZLC 2.5Y 4 2</td>
<td>2.5Y 4 2</td>
<td>2.5Y 4 1</td>
<td>2 PO 2-10mm</td>
<td>2</td>
</tr>
<tr>
<td>at 3.0</td>
<td>3Bck</td>
<td></td>
<td>SPM slope deposits (breccia coll. + clay skins)</td>
<td>ZCL- 4Y 4 3</td>
<td>4Y 4 3</td>
<td>4Y 6 3</td>
<td>0.5 SB 10-20mm</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CDS2 Pedal soil material, adjacent section</th>
<th>Depth</th>
<th>Hor</th>
<th>Unit description</th>
<th>Field Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Soil Structure</th>
<th>React HCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>~</td>
<td>B2</td>
<td></td>
<td>Hi. structured B2 horizon</td>
<td>ZLC 2.5Y 5 4</td>
<td>2.5Y 5 4</td>
<td>2.5Y 7 3</td>
<td>3 PO 2-5mm</td>
<td>2</td>
</tr>
</tbody>
</table>

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Field, laboratory and microscopy data

Table 4.1 indicates the soil parent materials are highly calcareous (strong reaction to dilute HCl) with the paleosol A horizons slightly less reactive to dilute HCl. The upper paleosol (0-1.3 m) has a silty light clay texture throughout while the overlying and underlying sediments have a similar though slightly siltier texture. Strong structural development (grade 3) is restricted to the topsoil of the first paleosol 2A11 and the B2 horizon of CDS2. Moderate grades (2) of structure occur in the other A-horizons. The dark soil colours (2.5Y 4/1 and 10YR 4/1) occur in the upper part of the paleosol but become very pale in the calcic horizon (2Ck). The calcic horizon contains abundant 30-50 mm sized, hard precipitated, calcium carbonate nodules suggesting a carbonate stage of II+ to III (Birkeland 1999) (see Plate 4.9 at 0.9-1.1 m). This would indicate a possible age of 50 – 150 kyr BP (Birkeland 1999).

Microscopic examination of samples demonstrated the strong angular pedality of the 2A11, 2A12 and 3A paleosols horizons, the peds having distinct waxy surfaces and mangans. Calcium carbonate is restricted to tubular pores and may be re-entering the paleosol from the highly calcareous loess-like material above. This has clear sub-vertical linear concentrations of calcium carbonate at its base, which could readily be leached to the paleosols below (Plate 4.8). The upper paleosol, at 0 – 1.1 m, has a distinct calcic horizon (2Ck) at 0.9-1.1 m (as measured from upper part of 1st paleosol) and micrographs of the nodules are provided in Plate 4.11. Below this is a second paleosol, quite similar to the one above with waxy peds, mangans and carbonate in root channels. This second paleosol forms above a gritty silty clay loam sediment that contains angular to rounded lithic fragments of 1-4 mm diameter range suggests they may have been derived as slope wash (3BCk). The material is highly porous and has soft carbonate precipitated in the pore walls (Plate 4.11).

Environmental scanning electron microscope examination of the 2A12 of CDS1 indicates the high crystallinity of the carbonate veins in the peds. Analysis of the images and spectra also show the waxy smooth clayey surfaces of the peds that appear to be smectite rich (Figure 4.5).
Plate 4.8 Site CDS1. Note the prominent very dark brown dipping paleosol with 3-5 cm dia. carbonate nodules in subsoil. The dark paleosol is buried by calcareous loess-like sediments. The section occurs on the catchment divide in the mid catchment 2.5 km E of Syndendron. Erosion of these fine textured sediments provide materials for debris flow deposits and alluvium e.g., Syndendron alluvium.

Plate 4.9 Site CDS1. Note site is located on the catchment divide and has been subject to severe erosion in both the Leipsokouki watershed (left-hand side) and the Grevenetikos catchment (right-hand side). Dip on the soil and underlying sediment suggest Pleistocene faulting in the area.
Plate 4.10  Site CDS2. Showing the deep, fine-texture soil horizons and sedimentary materials on the catchment divide. The highly structured or “pedal” soil sample CDS2 was taken from the upper section as indicated on the plate.

Figure 4.4  Location of sites CDS1 and CDS2 on the catchment divide. Note very steep slopes and gullies to the south which descend into the Grevenetikos river valley. Gentler slopes descend into the Leipsokouki valley to the north. Arrows mark sites. Contours at 10 intervals, road marked as duel thin line at tip of arrows, north is top of page, gully shown with orientated short stoke lines. CDS2 site also marked, see Plate 4.10.
Data in Table 4.1 and also Plate 4.11 indicate the very strong soil structure of the CDS2 B2 horizon. The micrographs indicate the soil was initially leached of carbonate but has received carbonate in cracks following burial by calcareous loess (Plate 4.12). The micrographs of CDS2 also show waxy ped surfaces and prominent manganiferrous coatings (mangans) on some peds. Examination of these mangans using an environmental scanning electron microscope (ESEM) indicates a manganese signal on the soil peds (see Figure 4.6). These features suggest a strongly developed soil horizon of moderate age. The images and spectra also indicate sub-rounded silt sized mica and quartz grains in a finer matrix.

Table 4.2 shows the organic carbon values are higher in the black paleosols upper horizons (2A11 and 2A12) although they are low values when compared to some of the modern soils. Retallack (2003) has indicated that an order of magnitude lower Walkley-Black organic carbon may occur in paleosols as compared to modern soils. Soil pH is alkaline as typical in calcareous soil materials. The materials are non-saline to slightly saline. The structured B2 horizon has lower carbon as would be expected in a subsoil horizon while the pH is also alkaline reflecting the calcareous nature of the parent materials. The high soil pH values of all CDS1 and CDS2 soil materials indicates even with considerable age the weathered soil materials have not been acidified. This suggests a low leaching environment has existed for a considerable period and also that the parent materials are base rich. The abundance of calcareous horizons supports this notion.

<table>
<thead>
<tr>
<th>CDS 1 Black calcareous paleosols</th>
<th>Depth (m)</th>
<th>Hor.</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC 1:5 µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>at -0.5 m</td>
<td>1C</td>
<td>Upper loess overlying black calcic soil</td>
<td>0.29</td>
<td>8.3</td>
<td>152</td>
<td></td>
</tr>
<tr>
<td>0-0.2 m</td>
<td>2A11</td>
<td>Topsoil of black calcic paleosol</td>
<td>0.47</td>
<td>8.3</td>
<td>163</td>
<td></td>
</tr>
<tr>
<td>at 0.4 m</td>
<td>2A12</td>
<td>Black calcic paleosols</td>
<td>0.39</td>
<td>8.3</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>0.9-1.1 m</td>
<td>2Ck</td>
<td>Calcic horizon, 30-50 mm carbonate nodules (stage III calcic)</td>
<td>0.00</td>
<td>8.4</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>1.1-1.3</td>
<td>3A1</td>
<td>Dark topsoil below calcic horizon</td>
<td>0.18</td>
<td>8.4</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>at 3.0 m</td>
<td>3BCk</td>
<td>SPM slope deposits with clay skins</td>
<td>0.08</td>
<td>8.5</td>
<td>94</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CDS2 Pedal B2 horizon</th>
<th>Depth (m)</th>
<th>Hor.</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC 1:5 µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedal soil</td>
<td>B2</td>
<td>Highly structured (pedal) B2 horizon</td>
<td>0.10</td>
<td>8.2</td>
<td>142</td>
<td></td>
</tr>
</tbody>
</table>
The scanning electron spectra and micrographs of the loess-like sediment (1C) capping the paleosols in the CD1 section indicate the material is highly calcareous and contains well rounded fine sand grains of talc and serpentine set in a finer silty clay matrix (Figure 4.6).

X-ray fluorescence and X-ray diffraction analysis

X-ray fluorescence data are presented for two horizons of site CDS1 and the B2 horizon of site CDS2 sample are presented in Table 4.3. The black paleosol upper horizons of CDS1 (2A11, 2A12) have low silica content, i.e., less than 50% and high amounts of calcium and magnesium oxides. The well-structured B2 horizon (CDS2) has 62% silica but lower calcium and magnesium oxide. The X-ray fluorescence data indicate silica, aluminium, calcium and magnesium oxides dominate in the black calcareous paleosol. The “loss” of 14-15% probably relates to crystalline water in the large amount of smectite present and also carbon present as carbonate and organic matter as shown in Tables 4.2 and 4.4. In the more finely pedal B2 horizon the silica, iron, potassium, sodium and titanium are more abundant and “loss” is only 6.5 percent. This sample has less calcite (see Table 4.4).

### Table 4.3 Major element (%) by X-ray fluorescence for CDS1 and CDS2

<table>
<thead>
<tr>
<th>CDS1</th>
<th>Depth (m)</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A11</td>
<td>0-0.2</td>
<td>46.25</td>
<td>0.52</td>
<td>10.00</td>
<td>8.56</td>
<td>0.13</td>
<td>7.24</td>
<td>10.55</td>
<td>0.50</td>
<td>1.20</td>
<td>0.07</td>
<td>14.97</td>
<td>99.98</td>
</tr>
<tr>
<td>2A12</td>
<td>at 0.4m</td>
<td>47.71</td>
<td>0.55</td>
<td>10.59</td>
<td>8.88</td>
<td>0.14</td>
<td>6.16</td>
<td>9.80</td>
<td>0.55</td>
<td>1.22</td>
<td>0.07</td>
<td>14.32</td>
<td>99.97</td>
</tr>
<tr>
<td>CDS2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>Pedal soil</td>
<td>62.20</td>
<td>0.70</td>
<td>13.97</td>
<td>7.20</td>
<td>0.07</td>
<td>2.50</td>
<td>3.08</td>
<td>1.24</td>
<td>2.17</td>
<td>0.07</td>
<td>6.48</td>
<td>99.68</td>
</tr>
</tbody>
</table>

The X-ray fluorescence data indicate the higher calcium contents of the black calcareous paleosols as anticipated from the strong reaction to dilute HCl (Table 4.1). High calcite (calcium carbonate) in the CDS1 horizons is indicated from X-ray diffraction analysis in Table 4.4. These dark horizons also have higher magnesium levels, and probably reflect the higher serpentine (Mg₃[Si₂O₅](OH)₄) content (Table 4.4). The X-ray diffraction data indicate that the black calcareous soils (CDS1) are dominated by smectite clays with quartz and calcite in moderate amounts, while serpentine is also in moderate proportions. The pedal B2 horizon (CDS2) is lower in calcite and serpentine but higher in mica and plagioclase. The higher silica content of CDS2 is likely due to the relatively higher quartz and plagioclase levels and lower
at - 0.5 m 1C
Loose, dusty with no structure (a), highly calcareous with few rounded 1mm lithics of serpentinite (c arrow), sediment = loess?

0 – 0.2 m 2A11
Buried paleosol with strong angular pedality with waxy surfaces, magans and carbonate in tubular pores

at 0.4 m 2A12
Buried paleosol, strong angular pedality, distinct carbonate in pores and mangans. Waxy surfaces

0.9 – 1.1 m 2Ck
Hard, crystalline, 30 - 50 mm calcium carbonate nodules set in soil matrix.

1.1 – 1.3 m 3A
2nd buried paleosol, strong angular pedality, with distinct soft carbonate in root channels and cracks, waxy ped surfaces with mangans.

at 3.0 m 3BCk
Gritty slope wash (a), with angular to rounded lithic fragments (b), soft carbonate in root channels (c).

Plate 4.11 Micrographs of soil materials in section CDS1 (scale in mm).
Figure 4.5 ESEM semi-quantitative spectral analysis and images of sample from buried soil in section CDS1 taken at 0.4 m depth. Spectra a) and image b) show calcium carbonate vein. The spectra a) and ESEM image b) confirm field identification with high Ca, O and moderate C levels. Spectra at c) and image d) show smooth fine smectite clay coating ped surface as indicated by XRD analysis (see Table 4.4) and the high Al, Si and O and moderate Mg. Some mica may also occur as indicated by the high K. Spectra at e) and image at f) show possible chlorite flake as indicated by high O, Si, Al and Mg, this is supported by the XRD and the size of the mineral shown in f)
Figure 4.6 ESEM semi-quantitative spectral analysis and images of sample from the “calcareous loess” which overlies the paleosols shown in section CDS1 (see Plate 4.8). Spectra a) and image b) show the calcareous loess with spectral peaks in O, Ca and C (calcite) as well as Mg and Al (probably smectite and serpentine). The soft calcium carbonate is coating the rounded grains of silt and fine sand (images b and d). The coarser grains shown in d) are probably serpentine and talc as they have very high Mg and Si levels.
calcite content. The higher potassium levels of CDS2 reflect far higher mica content, while the high sodium is probably a reflection of higher plagioclase levels. The higher aluminium levels probably reflect a higher amount of the alumino-silicates smectite and mica.

One interpretation of the data is that the dark paleosols horizons (2A11 and 2A12) have high amounts of serpentinite and very high level of smectite. They also have moderate amounts of manganese a feature of black vertosols (Osok and Doyle 2004).

Table 4.4  Data on X-ray diffraction for CD1 and CDS2

<table>
<thead>
<tr>
<th>CDS1</th>
<th>50-70%</th>
<th>35-50%</th>
<th>15-25%</th>
<th>10-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A11, 0-0.2m</td>
<td>Smec.</td>
<td>Qtz</td>
<td>Calcite</td>
<td>Serpentine</td>
<td>Chl., Plag., K-Feld.</td>
<td>Mica, Dolo., Talc, Amph.</td>
<td></td>
</tr>
<tr>
<td>2A12, 0.4m</td>
<td>Smec.</td>
<td>Qtz</td>
<td>Calcite</td>
<td>Serpentine</td>
<td>Chlorite, Plag.</td>
<td>K-Feld., Mica, Talc, Amph.</td>
<td></td>
</tr>
</tbody>
</table>

In summary the two types of soil materials have the same range of minerals and broadly similar XRF chemistry. The main differences are the more siliceous nature of the “pedal B2 horizon”, a reflection of higher mica and plagioclase content and lower calcite and serpentinite. All these materials indicate the cover beds and associated paleosols are very base rich, fine textured, high pH and calcareous materials formed from reactive clay and silts (smectite and mica) that are quartz, calcite and serpentinite rich. They appear to release much carbonate on weathering that is re-precipitated in subsoils as nodules and veins. The provenance of the materials is likely to be mixed loess derived from Pleistocene gravelly stream beds that were dominated by basic igneous rocks such as gabbro, diabase and weathered ultramafics and with moderate amounts of limestone and minor sandstone.

Beneath soil sections CDS1 and CDS2, exposed in a gully head on the Grevenitikos River side of the drainage divide, is a discontinuous layer of sub-rounded and rounded, clast-supported stones and boulders (dia. 100 – 250 mm). These are composed of mostly sandstone and siltstone and overlie a carbonate rich layer with distinct nodules and appear to rest on the Tertiary strata. This stony basal layer is capped by a brownish paleosol. The stones are clast-supported and water worn and thus may represent the Plio-Pleistocene gravel facies, though richer in sandstone and
Plate 4.12 Micrographs of the CDS2 sample, a pedogenic horizon within the Plio-Pleistocene cover beds adjacent to site CDS1 (see Figure 4.2). Note waxy surfaces on peds (a, b), very strong angular pedality (a, d), carbonate in some cracks (d, f), root channels (f), distinct mangans (b, c, e), variegated colour pattern in some peds (c). All features suggest a strongly developed soil horizon (scale in mm).

AB horizon at 0.15 m.
Very strong, angular pedality with shiny surfaces, distinct reddish hue

B2 horizon at 0.6 m
Very strong, angular pedality (a), some smooth surfaces and lithic fragments (b)

Ck horizon at 1.1 m
Well developed hard 10-20 mm calcium carbonate nodules (b) and filling pores (a)

Plate 4.13 CDS-Red soil that exhibits many features of strongly developed soils including, red hues, strong pedality and well developed calcium carbonate nodules suggesting Stage II+ or III. This would suggest an age in the range 50 – 150 Ka (scale graduations in mm).
Figure 4.7 ESEM semi-quantitative spectral analysis and images of sample from buried strongly pedal soil in section CDS2. Spectra a) was taken of the surface of what was field identified as a manganese coating (mangan) and the spectra confirms this with a Mn spike. The spectra b) and ESEM image c) show a silt sized mica flake in the fine soil matrix as indicated by XRD and the high O, Si and Al and moderate K in spectra. The spectra d) and image at e) show a silt sized quartz crystal set in the fine matrix dominated by smectite and mica as indicated by high O, Si, Al and moderate K and Mg levels in spectra.
thus locally derived. Their position at the base of the cover beds would indicate they represent a stone-line or erosional lag deposit.

**Site CDS-Red - Terra Rossa on catchment divide**

**Introduction**

Located 1.8 km SE of the village of Rodia site CDS-Red is a Terra Rossa soil having reddish brown upper profiles with calcareous lower subsoils (40.1370° N and 21.3502° E). Terra Rossa type soils are developed on the catchment divide above Tsifliki (see Plate 4.13). Several of these soil profiles were described by Doyle (1990), refer sites P81 and P82, and exhibit strong pedality and strong reddish hues (5YR and 7.5YR). They classify as Red Ferrosols in the Australian Soil Classification (Isbell 2002). In the current study the whole soil mineralogy, basic chemistry and major oxide composition is examined as erosion of these materials may supply soil-like colluvium to the mid and lower slopes under study.

**Field, laboratory and microscopy data**

These soils are well structured with neutral to alkaline pH, a gradational texture profile, abundant calcium carbonate in the subsoils with 10-20 mm calcium carbonate nodules (Plate 4.14 and Tables 4.5 - 4.6). The reddish brown hues are supported by moderate iron oxide content of 8-9% (Table 4.7). The soil colours indicate a major proportion of iron must be as “free” iron oxides although the iron oxide mineral goethite and hematite were not identified in the whole soils XRD analysis, probably due to weak crystallinity (see Table 4.8). Doyle (1990) showed that the clay mineralogy of the reddish brown soils in the upper valley are dominated by mica clays as compared to the darker soils in the valley which exhibited strong smectite XRD traces. Yassoglou et al. (1997) have indicated soils become darker purple as the smectite content increases in red soil environments of Greece. Singh (1954) has shown reactive smectite clays commonly develop a very close association with soil organic matter which leads to the darker colours in vertisols and vertic mollisols.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Hor Description</th>
<th>Field Text.</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Devel Ty Size</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>at 0.15</td>
<td>AB</td>
<td>CDS-Red lower topsoil</td>
<td>LC</td>
<td>7.5YR 4</td>
<td>3</td>
<td>PO</td>
</tr>
<tr>
<td>at 0.6</td>
<td>B2</td>
<td>CDS-Red subsoil</td>
<td>ZLC+</td>
<td>10YR 3</td>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>at 1.1</td>
<td>Ck</td>
<td>CDS Calcic horizon</td>
<td>ZCL+</td>
<td>10YR 4</td>
<td>3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 4.5  **Field data for CDS-Red soil**
Table 4.6  Laboratory analysis of CDS-Red soil

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Hor.</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 Soil:water</th>
<th>EC µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>at 0.15</td>
<td>AB</td>
<td>CDS-Red lower topsoil</td>
<td>0.50</td>
<td>7.1</td>
<td>208</td>
</tr>
<tr>
<td>at 0.6</td>
<td>B2</td>
<td>CDS-Red subsoil</td>
<td>0.32</td>
<td>7.8</td>
<td>161</td>
</tr>
<tr>
<td>at 1.1</td>
<td>Ck</td>
<td>CDS Calcic horizon</td>
<td>0.17</td>
<td>8.3</td>
<td>120</td>
</tr>
</tbody>
</table>

Microscopy of samples from the AB and B2 horizons in this soil indicated a very strong, angular pedality with shiny, smooth ped surfaces and distinct reddish hues (Plate 4.13). The micrographs also show the well-developed, 10-20 mm sized, calcium carbonate nodules formed in the Ck horizon at the base of the profile (Plate 4.12). Most pores in the soil matrix are filled with calcium carbonate also.

**X-ray fluorescence and X-ray diffraction analysis**

Interestingly the aluminium oxide levels are very high in the A1 and B2 – the highest of any sample in the catchment; perhaps a reflection of the chlorite and mica levels (Table 4.6). The soil profile forms on calcareous colluvium derived from mudstone and fine sandstone lithic fragments. This soil is actively eroding and observation of debris flow material lying lower in the valley would suggest wasting by mass movement was also an issue in the past at this site (see site C11 and C1 described in Chapters 5 and 7).

The XRF data are presented in Table 4.7 and Graph 4.1 show that silica, titanium and aluminium oxides are highest in the topsoil indicating greater weathering in the part of the profile. The level of calcium is quite low in the topsoil when compared to the CDS1 and CDS2 soils. Calcium increases a little in the B2 and then abruptly in the Ck horizon reflecting leaching from the soil materials above. The Ck horizon has well developed nodules of calcium carbonate as can be seen from micrographs shown in Plate 4.13. Quartz is also highest in abundance in the topsoil and decreases with depth while smectite increases in the subsoil. The “loss” is highest in the Ck horizon and probably reflects water and carbon losses associated with the carbonate present. The soil has moderate plagioclase, chlorite and mica levels, although the subsoil is dominated by smectite.
Table 4.7  Major element (%) by X-ray fluorescence for CDS-Red soil

<table>
<thead>
<tr>
<th>CDS-R</th>
<th>Depth (m)</th>
<th>SiO2</th>
<th>TiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na2O</th>
<th>K2O</th>
<th>P2O5</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.15</td>
<td>58.21</td>
<td>0.80</td>
<td>16.04</td>
<td>8.41</td>
<td>0.13</td>
<td>3.78</td>
<td>1.35</td>
<td>1.29</td>
<td>2.61</td>
<td>0.06</td>
<td>7.28</td>
<td>99.96</td>
</tr>
<tr>
<td>B2</td>
<td>0.6</td>
<td>54.22</td>
<td>0.69</td>
<td>15.08</td>
<td>8.97</td>
<td>0.09</td>
<td>4.69</td>
<td>4.33</td>
<td>1.13</td>
<td>2.19</td>
<td>0.05</td>
<td>8.60</td>
<td>100.04</td>
</tr>
<tr>
<td>Ck</td>
<td>1.1</td>
<td>36.57</td>
<td>0.46</td>
<td>9.99</td>
<td>5.75</td>
<td>0.07</td>
<td>4.33</td>
<td>19.91</td>
<td>0.95</td>
<td>1.77</td>
<td>0.11</td>
<td>20.44</td>
<td>100.35</td>
</tr>
</tbody>
</table>

Graph 4.1  Major elemental oxide trends in soil CDS-Red

The clay mineralogy of the CDS-Red soils is not as strongly dominated by smectite as the black calcareous paleosols (CDS 1) and has higher mica and chlorite, a feature thought to affect soil colour (Doyle 1990). Calcite or pedogenic calcium carbonate is 25-35% in the Ck horizon and supports the field evidence of leaching of carbonate from the upper profile and it’s accumulation as nodules in a well developed calcic horizon. Quartz is most abundant in the topsoil and decreases with depth.

Table 4.8  X-ray diffraction data for CDS-Red soil

<table>
<thead>
<tr>
<th>CDS-Red</th>
<th>35-50%</th>
<th>25%-35%</th>
<th>15-25%</th>
<th>10-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red CK</td>
<td>Smec., Calcite</td>
<td>Quartz Chl., Mica, Plag.</td>
<td>Serpentine, K-Feldspar, *</td>
<td>Dolomite</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In summary these reddish brown well structured soils with distinct carbonate horizons provide an indication of the likely nature of the soil cover prior to the erosion and burial seen during the Holocene in the catchment. The presence of these soils on the catchment divide and upper slopes indicate their erosion could supply much fine textured, well structured and calcareous sediment to the lower slopes and valley floor.
Plate 4.14 Site CDS-Red an example of a mature “Terra Rossa” soil profile. It forms on the catchment divide above Tsifliki (erosion of this soil by mass movement see C1 and C11). The soil has a well developed calcic horizon (stage II+), very strong soil structure and strong red hues (5YR) in the B2 horizon. See CDS-Red micrographs of A1, B and Ck horizons in Plate 4.12.

Figure 4.8 Site CDS-Red on the catchment divide above Tsifliki (erosion of this soil by mass movement leads to deposition at sites like C1, C11 and also P41 of Doyle 1990).
Site CDS3 - Colluvial soil deposited in prior gully

Introduction
This site is located on the Syndendron – Rodia ridge road approximately 1.9 km SE of Rodia at 40.1344\(^{0}\) N and 21.3528\(^{0}\) E (see Plate 4.14 and Figure 4.9). The modern profile was described as soil P78 by Doyle (1990). During this investigation the entire stratigraphy of the section is examined and sampled. The site rests on the catchment divide, falling on the Leipsokouki stream side. The modern soil appears to be formed within colluvium deposited in a prior gully (refer Plate 4.14). Following the incision of the gully, soil colluvium was deposited on the gully sides and floor (Plate 4.15).

Field, laboratory and microscopy data
The modern soil profile is leached of carbonate in the upper part and has a well-developed calcareous subsoil (Table 4.10 and Plate 4.15). The profile has an alkaline pH profile. The organic carbon profile shows an abrupt decline with depth. The moderate organic carbon levels in the topsoil may be the reason for lower soil pH. The soil horizons are slightly saline. Reaction to dilute HCl indicates a leaching of carbonate from the upper profile in both the modern and buried soils. Soil structure is strong in both the modern topsoil and the buried subsoil (2B2 horizon). Microscopy indicates the B1 of the modern soil contains rounded lithic fragments up to 30 mm in diameter (Plate 4.16) supporting the notion it is derived from slope deposits. Larger pieces of sandstone were identified in the field in this layer. The modern soil also has carbonate nodules of dominantly 5-10 mm diameter although some elongate nodules may be as much as 20 mm. The modern soil and colluvium bury a partly truncated soil which forms on the gully floor. This buried soil material has strong pedality, distinct mangans, grooved slicken-side surfaces and “hallows” of maganiferrous matrix on the outer edge of most peds (see Plate 4.16). The nature of the mangans was confirmed using ESEM spectra that show a manganese peak (see Figure 4.10). The lower subsoil (2Ck) of the buried soil has hard, crystalline calcium carbonate nodules forming within the weathering fine sandstone substrate. These pedological features suggested the buried soil (2B2 and 2Ck) is of considerable age and despite being truncated by erosion the lower profile appears in situ. The abundance of nodules, their size and hardness would indicate stage II+ to III carbonate development and thus the buried soil may be in the order of 50 – 150 kyr in age (Birkeland 1999).
Plate 4.15  Site CDS3 on catchment divide above Tsifliki. Note inset fill with truncated soil at sides (arrows) and truncated B2 and Ck at base. Lower section is bedrock, Ck has formed in situ in the bedrock.

Figure 4.9  Site CDS3 and CDS-Red on the catchment divide above Tsifliki (erosion of this soil by mass movement leads to deposition at sites like C1, C11 and also P41 of Doyle 1990). Contour interval is 4 m.
Plate 4.16 CDS3 showing moderately developed soil over strongly developed soil with large carbonate nodules (scale in mm)
Figure 4.10 ESEM semi-quantitative spectral analysis and image of sample from CDS3 2B2 horizon with distinct mangans and slicken-sides. The spectra above was taken of the surface of what was field identified as a manganese coating (mangan) and the spectra confirms this with a Mn spike. The high O, Si and Al and moderate Mg and K in spectra and fine-texture of the matrix suggest the minerals smectite and mica are also present.
Table 4.9  Field description data for section CDS3

<table>
<thead>
<tr>
<th>Depth</th>
<th>Hor.</th>
<th>Description</th>
<th>Field Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Devel</th>
<th>Typ</th>
<th>Size</th>
<th>React</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.30</td>
<td>A1</td>
<td>A1 of modern topsoil</td>
<td>ZLC-10YR</td>
<td>4 10YR</td>
<td>3</td>
<td>PO</td>
<td>2-5mm</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0.30-1.2</td>
<td>B1</td>
<td>B1 of modern soil</td>
<td>ZCL-2.5Y</td>
<td>5 2.5Y</td>
<td>3</td>
<td>PO</td>
<td>2-10mm</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1.2–2.9</td>
<td>Ck</td>
<td>Calcic horizon</td>
<td>ZCL-5Y</td>
<td>6 5Y</td>
<td>2</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9–3.1</td>
<td>2B2</td>
<td>Buried soil, slickensides mangans</td>
<td>ZLC-2.5Y</td>
<td>5 2.5Y</td>
<td>2</td>
<td>AB</td>
<td>50-100mm</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3.1+</td>
<td>2Ck</td>
<td>Calcic horizon in rock</td>
<td>ZCL-5Y</td>
<td>6 5Y</td>
<td>2</td>
<td>SB</td>
<td>5-10mm</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.10  Laboratory data for samples taken at section CDS3

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Hor.</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC μS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.30</td>
<td>A1</td>
<td>A1 of modern topsoil</td>
<td>1.87</td>
<td>7.5</td>
<td>238</td>
</tr>
<tr>
<td>0.30-1.2</td>
<td>B1</td>
<td>B1 calcareous</td>
<td>0.54</td>
<td>7.9</td>
<td>230</td>
</tr>
<tr>
<td>1.2–2.9</td>
<td>Ck</td>
<td>Calcic horizon</td>
<td>0.31</td>
<td>8.3</td>
<td>225</td>
</tr>
<tr>
<td>2.9–3.1</td>
<td>2B2</td>
<td>Buried soil, slickensides, mangans, hard peds</td>
<td>0.26</td>
<td>7.8</td>
<td>232</td>
</tr>
<tr>
<td>3.1+</td>
<td>2Ck</td>
<td>Calcic horizon in bedrock</td>
<td>0.31</td>
<td>8.3</td>
<td>167</td>
</tr>
</tbody>
</table>

In summary this site indicates gully development has extended to the catchment divide in the past. The site contained no charcoal and so was not radiocarbon dated. The site also indicates that fine textured calcareous colluvium and soil material filled the gully sufficiently long ago so as to allow for the development of a distinct soil profile with calcareous subsoils. It is likely that such gullies could act as pathways for fine sediment to be concentrated and transported to the lower valley slopes.

Site CDS4 Plio-Pleistocene cover beds on upper slopes and benches

This site is located at 40.114° N and 21.387° E in a gully head in the mid catchment (Figure 4.11 and Plate 4.16). The site provides a demonstration that the upper fine-textured Plio- Pleistocene cover beds extend off the divide and down the upper slopes, at least in the mid and lower catchment. The cover beds are clearly shown in Plate 4.2 at an elevation of 670 m and can be seen to extend down to 640 m asl in the gully wall exposures. The cover beds appear to mantle the ridgelines, hilltops and gentle upper slopes lying above approximately 630 m. They may also control gully morphology as can be demonstrated in Figure 4.11. The gullies rapidly widen and deepen in terrain where the Plio- Pleistocene cover beds overlie the Tertiary bedrock. Perhaps a hydraulic hiatus at the boundary of the two units accelerates the erosion rate
leading to very steep walled, wide gullies. Seeps were noted in several gully walls at
the height of summer and water springs are surprisingly common at higher elevations
in the mid and upper catchment while restricted to the valley floors in the lower
catchment. The location of archaeological sites and modern villages supports this
interpretation as all are in the mid and upper catchment and at elevations above 630
m, i.e., at or above the Mersina surface.

Only two samples were taken from the section. The section stratigraphy is given
below (refer to Plates 4.16 – 4.17).

<table>
<thead>
<tr>
<th>Depth</th>
<th>Code</th>
<th>Description Steam</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.7 m</td>
<td>1C1</td>
<td>Pale yellow, fine textured, banded alluvial slope wash, deposited on slight dip down valley.</td>
<td></td>
</tr>
<tr>
<td>0.7 – 1.8</td>
<td>1C2</td>
<td>Light olive brown, weak blocky structure, soil-like material with gritty fragments in silty clay matrix, lithic fragments dominantly sub-rounded to round and 1 - 15 mm dia. Calcium carbonate lines pores (see Plate 4.17-a). The carbonate appears to be derived from angular lithic fragments of carbonate (1-3 mm). Material is likely to be slope wash.</td>
<td></td>
</tr>
<tr>
<td>1.8 – 2.0 m</td>
<td>1C3</td>
<td>Pale yellow, calcareous silty clay, otherwise similar to material above.</td>
<td></td>
</tr>
<tr>
<td>2.0 – 4.8 m</td>
<td>2B2</td>
<td>Buried truncated paleosol from Plio-Pleistocene sequence as indicated by tuff blocky peds, with grooved, mangan-coated surfaces and distinct “hollows” on ped surfaces (see Plate 4.17). Also calcans on some grooved ped surfaces that react to dilute HCl while remainder of soil matrix does not. When sample is washed, shaken and suspended sediment poured off sand-sized micro-aggregates remain. These micro-aggregates can be smeared when soft indicating they are clayey (see ESEM images in Figure 4.13).</td>
<td></td>
</tr>
<tr>
<td>4.8 – 6 m</td>
<td>2BC</td>
<td>Rounded and sub-rounded gravels and stones (20-200 mm) deposited on sloping bedrock platform. This layer forms a distinct stone-line separating the Tertiary bedrock from the Plio-Pleistocene cover beds.</td>
<td></td>
</tr>
<tr>
<td>6 m+</td>
<td>R</td>
<td>Tertiary bedrock.</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.11 Plate shows two gullies depicted on a topographic map. Site CDS4 is located in a gully head, 400m below the Grevena – Syndendron road which runs along the catchment ridge/divide. The 1:5,000 topographic map (contours at 4 m) highlights the sediment storage in the heads of some valleys, a fact highlighted by straighter and more open contour pattern (see dashed circle). The valley fills may aid gully development by supply of seepage water and by their unconsolidated fine textured nature.
Plate 4.17 Site CDS4 deep fill materials in gully head. Age is unknown but the upper 2 m of fine-textured slope wash resembles the Syndendron alluvium (see Chapter 5). The more highly developed pedogenic features of the materials below 2 m suggest they may be Plio-Pleistocene.

Plate 4.18 Micrographs of sediments from site CDS4 which is located upstream of the large gully shown in Plate 4.2. Micrographs show two samples CDS4 at 0.6-1.7 m (a and b) and CDS4 2B2 horizon 2-4.8 m (mangans c-f). Micrographs of CDS4 1C2 images a & b show rounded 1-2 mm grit in silty matrix with calcium carbonate lining pores (a), and 2 - 15 mm rounded grit and gravel with carbonate in pores and cracks (b). Micrographs of CDS4 2B2 horizon show many distinct mangans (c – d), slicken-sides (e, f) and thick calcans over mangans over slicken-sides (e, f). Soil CDS4 2B2 (c-f) has vertic properties as indicated by mangans within ped but mixed and absent on outer ped material in d. Features indicate very well developed soil materials (scale mm).
Figure 4.12 ESEM semi-quantitative spectral analysis and image of sample from CDS4 0.6-1.7 m “Gritty slope wash” horizon. The spectra show high amounts of calcite a) and dolomite b) in this highly calcareous material which buries a well developed B-horizon (see below). This is shown by high O, Ca and Mg as well as moderate C in the spectra. Material may be Syndendron alluvium.

Figure 4.13 ESEM semi-quantitative spectral analysis and image of are from CDS4 2B2 horizon. This particular sample was prepared by swirling the soil in distilled water and pouring off the suspension to leave the water-stable aggregates and sand grains. The spectra a) and image b) show angular nature of the quartz grains (quartz is indicated by high O and Si). Spectra c) and image d) show the water stable clay aggregates mixed with angular and sub-angular quartz grains.
Table 4.11  Field and laboratory data of material sample at site CDS4

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Hor</th>
<th>Description</th>
<th>Field Text.</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev Ty Size</th>
<th>HCl React water</th>
<th>pH</th>
<th>EC uS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7-1.8</td>
<td>1C2</td>
<td>Gritty slopewash</td>
<td>ZCL</td>
<td>2.5Y 5</td>
<td>3</td>
<td>5Y 6 3</td>
<td>1</td>
<td>AB 5-20mm</td>
<td>3</td>
</tr>
<tr>
<td>2.0-4.8</td>
<td>2B2</td>
<td>Buried Plio-Pleist</td>
<td>ZLC</td>
<td>2.5Y 5</td>
<td>3</td>
<td>2.5Y 6 3</td>
<td>3</td>
<td>AB 20-50mm</td>
<td>0</td>
</tr>
</tbody>
</table>

A distinct stratigraphic break occurs at 2 m with quite different materials above and below this level. The lower materials have a high degree of pedogenic character while the materials above are gritty and calcareous suggesting they are more recent (Plate 4.16 and 4.17). The lower highly pedogenic materials appear to part of the Plio-Pleistocene cover beds and the gravelly layer (2BC) at the base of the section is similar to that seen underlying sites CDS1 and CDS2. In all three sites a gravel lag rests on the Tertiary bedrock.

In summary this site provides an excellent further example of the stratigraphy and process in the landscape. Although lacking dating the site indicates the Tertiary strata are capped by fine textured Plio-Pleistocene soil materials with distinctive pedogenic features. The boundary between the bedrock and fine Plio-Pleistocene sediments is marked by a stone-line which is typical of an erosional contact. The Plio-Pleistocene sediments appear to be truncated and capped by younger highly calcareous sediment. This younger sediment lacks pedogenic features and contains rounded lithic grit sized fragments in a silty clay matrix, typical of slope wash. However the age of this sediment is not known. No charcoal was apparent in the section.

**Summary of catchment divide sites**

In summary the key soil materials located on the ridge line range from dark, calcareous reactive silty clays soils rich in smectite, quartz, calcite and serpentine to reddish brown Terra Rossa soils with less smectite and calcite but more quartz, plagioclase and chlorite. Knowledge of the properties of these soil materials will help with interpretations provenance for soil and soil-like colluvial deposits in the lower landscape.

**Mature soils on valley slopes**

In some parts of the mid slopes of the valley can be seen well-developed soil profiles, some are truncated others are buried. These soils do not appear to be relict soils or exposed prior pedoderms but are modern soils developed on bedrock or slope deposits.
They indicate sufficiently stable soil forming conditions have existed in the past for the development of moderately deep soil profiles (1-2 m). Also more recent erosion of these soils may provide a source of pedogenic colluvium for sites on the lower valley slopes. While the CDS-Red site provides one example of a well-developed modern soil on the upper slopes of the valley, several examples for mid slopes are briefly discussed here. The mature soil types in this environment typically develop distinct calcareous subsoils. The calcic horizons commonly exhibit both vein and nodular calcium carbonate with hard nodules of moderate size (5-20 mm) forming in growth position in some profiles (e.g., CDS-Red, C7 and P60). These hard precipitated nodules, although not dated, provide a clue to the age of these soils.

**Review of Soil Profiles P38, P60 and P61 from Doyle (1990)**

Prior to examining examples from the current study Doyle (1990) has described well-developed, dark, reactive clay soils (P38, P60 and P61) which lie down slope of site CDS4 and above the adjacent gully (P38 latitude 40.11650° N and longitude 21.39080° E; P60 4011570° N and 2139230° E; P61 4011370° N and 21.39480° E, see Appendix 2 for soil profile descriptions). All the soil profiles (P38, P60 and P61) have distinct calcareous subsoil horizons. Profiles P60 and P61 are exposed at the head of large gullies in the mid catchment (see Plate 4.19 and Figure 4.11). Soil profile P60, including the underlying calcic horizon, is over 3 m deep. However, a stone-line at 1-1.5 m depth suggests the upper and lower profiles are separate depositional materials. The fact the calcic horizon has abundant calcium carbonate nodules and much soft carbonate filling cracks and pores indicates the profile is of considerable age, calcium carbonate stage II i.e., ca 20 Kyr in age (Birkeland 1999).

Soil profiles P38 and P61 have the well-developed calcic horizons and also strongly structured subsoils, but both profiles are thinner in the solum and truncation is a possibility in both profiles. Truncation and subsequent burial is clearer in P61 as the well-developed; stone free, strong brown B-horizon is capped by a light grey, highly calcareous slope wash with sub-rounded gravels (see Appendix 2).
Plate 4.19 Soil profiles P60, P61 and P38 from Doyle (1990) illustrating a mature clayey soil profile with strongly developed calcic horizons (some Stage II). These soils occur in the mid slope positions and two exposed in an active gully head (see Figure 4.6). The high degree of soil development suggests moderately stable conditions prior to gullying at P60 and P61.

Figure 4.14 Site C7 located in the adjacent Amygdaliotikos stream which is a tributary of the Leipsokouki (contour interval is 20 m).
Figure 4.15 Particle size analysis of soil profiles P38 and also P37 (see Chapter 5). The data show the high clay and silt content of the mature soils in the valley (after Doyle 1990). P38 represents an example of a well developed vertisol likely to have only suffered minor topsoil erosion during the Holocene. The IIIAb horizon of soil profile P37 is a soil dated to 9.3 kyr BP which forms on the Syndendron alluvium, its upper horizons (Au1 and Au2) being derived by soil creep from adjacent soil covered slopes.
These three soils indicate that much of the Leipsokouki upper landscape was capped by well-developed soil profiles that could act as a source of clayey, dark, pedogenic colluvium for lower slopes (refer to Figure 4.15).

**Site C7 - Amygdalies double fill**

This site is located 700 SW of the village of Amygdalies at latitude 41.1508° N and longitude 21.3680° E (see Figure 4.15 and Plates 4.20 – 4.21). The site is within the adjacent, and tributary, Amygdaliotikos drainage basin. The site shows a well-developed in situ buried soil profile with a strong prismatic 3B2 and calcic 3Ck horizons with hard precipitated calcium carbonate nodules in growth position in the bedrock (Plates 4.20 - 4.21). This soil forms on mudstone bedrock and has been buried by deposits of approximately 3 m thickness. The lower 1-1.5 m of covering deposits appear to be slope wash as indicated by sorting and faint bedding. This slope wash is in turn capped by up to 1.5-2 m of colluvium with a pedogenic character. The site indicates stable soil forming conditions occurred prior to de-stabilization and erosion at the site prior to burial by water borne slope wash sediment. Subsequently a soil-derived colluvium has buried the slope wash deposits.

**Field stratigraphy**

Depths depend on which part of the section is measured (see Plate 4.20).

0 – 2 m 1AB Brown (10YR 4/4); sandy clay loam; moderately developed angular blocky structured colluvium. This material is hard when dry and appears to be a soil-like colluvium.

2 – 3.6 m 2C Lighter coloured slope wash deposits with thin (10cm) lenses of grit and sandy texture. Piece of charcoal collected from the lower part of this unit (at a depth of 1.6 – 1.8 m from the surface as the upper soil colluvium is thinner at this part of the section).

3.6 – 4.0 3B2 Truncated buried soil profile; brown (10YR 4/4) matrix colour; very strongly developed 50-100 mm prismatic structure breaking to strongly developed blocky structure; distinct manganese dendrites on hard ped surfaces. Calcium carbonate coating cracks in lower part of horizon and few hard 1-2 cm calcium carbonate nodules.
Plate 4.20  Site C7 Amygdalies double fill - Photo shows soil at base of section (reddish brown) formed on fine sandstone has been buried by colluvial and slope wash material in center (light greyish brown) and then this is capped by soil-like colluvium in upper photo. Close-up view of basal soil can be seen in Plate 4.19

Plate 4.21  Site C7 - Close-up of basal soil with carbonate in cracks in bedrock and small nodules (1-2 cm) in situ carbonate nodules which indicate the soil formed in place and is of considerable age. This profile lacks charcoal.
4.0 – 4.5 m  3Ck  Calcium carbonate deposits in cracks and joints of weathered mudstone; distinct hard precipitated 10-20 mm calcium carbonate nodules in growth position within the weathered bedrock.

The C7 section indicates a landscape with mature calcareous brown soils formed on mudstone were able to develop on what must have been relatively stable slopes of the catchment. The degree of soil development is indicated by the strong prismatic structure and the degree of leaching of pedogenic carbonate in the profile and the formation of 10-20 mm sized calcium carbonate nodules and veins *in situ* within the bedrock at the base of the soil. This has been followed by profile truncation and buried with up to 1.6 m of slope wash material. This indicates this site was in the transitional zone (Butler 1959) and acted as a conduit for sediment transport to lower slopes with minor erosion occurring at the site. Following this the section was buried by a thick (2m), homogenous, soil-like colluvium derived from adjacent slopes still carrying a soil cover.

It is unfortunate that insufficient charcoal could be collected from this site as radiocarbon dating would have provided useful information on the timing of these events. Notwithstanding this the key information provided by this site is the observation that well-developed soils did occur on some parts of the valley sides prior to a phase of active erosion and deposition of slope wash. This was followed by burial of the site with soil-like colluvium.

**Site C10 Buried brown soil on bedrock above Tsifliki**

A further example of a well-developed soil profile (C10) on the mid slopes of the valley occurs on the road leading from Tsifliki to the village of Amygdalies. The site is at and latitude 40.14170° N and longitude 21.36170° E (see Figure 4.16 and Plates 4.22 – 4.23). The section reveals a dark brown soil formed on the bedrock that has been buried by ashy colluvium, slope wash and more recent calcareous colluvium. The site shows a series of colluvial fills occur separated by a thin slope wash deposit. The site demonstrates important processes acting on some slopes in the catchment. The whole section is now being re-incised by a small gully.
Field stratigraphy

Listed below is the thickness of the horizons measured at their thickest exposed part, which is not necessarily the maximum thickness.

1.0 m  Greyish brown, calcareous, silty clay loam, colluvium with clear stone-line marking the base of unit, few pot sherds embedded in stone-line

1.2 m  Light yellowish brown (2.5Y 6/3), silty clay loam, soil-like colluvium.

0.2 m  White (5Y 8/1), fine sandy and silty slope wash, bedding evident in section, indicates water transported and sorted.

0.4 m  Light grey (5 Y 7/2), silty clay loam, soil-like colluvial which contains small amounts of charcoal.

0.9 m  reddish brown (5YR 5/4), silty light clay, strongly developed angular blocky structure, no stones, profile overlies mudstone-siltstone bedrock, common sub-angular 20 – 60 mm stones of sandstone.

R    Bedrock of bedded fine sandstone and mudstone.

Summary of site

The whole section lies in a concave competent of the slope, i.e., a channel-depression (see Figure 4.15). A well-structured soil has developed on the Tertiary bedrock on the valley slopes. There is no distinctive calcareous subsoil and the sub-angular coarse fragments in this soil profile suggest it may be partly colluvial in origin. This soil has then been capped by colluvium containing coarse fragments set in silty clay loam matrix. This colluvial material has been covered by fine textured slope wash. The last phase of deposition has involved the deposition of a further 2.2 m of colluvial materials deposited in two phases. The nature of the filling of this slope depression can be best shown in Plate 4.23 and Figure 4.16. This plate shows how the concave slope depression has acted as a pathway for colluvia and slope wash to move from the upper plateau and hill slopes to the lower terrace and strath surfaces in the catchment. The site provides an excellent example of two key types of slope deposit – one water derived silty-sandy slope wash and the second creep transported soil colluvium.

Discussion

This chapter has provided an introduction to the nature of the catchment and descriptions of some of the older soil materials on the mid and upper valley slopes. The catchment divide is the most logical place to find the oldest soil materials in the
Plate 4.22 Site C10 shows well developed soil profile developed on bedrock, capped by more recent colluvium and slope wash. Although ash and small amounts of charcoal occurred in the ashy colluvium above the brown soil, it was not sufficient for dating.

Figure 4.16 Site C10 near Tsifliki in the upper catchment, contour interval is 4m. The site is currently being re-incised by a small gully as indicated.
Plate 4.23 Site C10 with severely eroded slopes on either side of the inter-fluve in which the C10 soils and sediments occur. The inter-fluve (channel) acts as a conduit for sediment moving from the upper slopes and upper plateau landscape to the valley floor.

Plate 4.24 The slopes around Tsifli. The steeper eroded slopes supply and transport sediment to the valley floor which is filled with (Syndendron) alluvium. The slopes supply colluvium which forms aprons that mask the alluvial fan landforms expression throughout the valley.
valley as erosion cuts progressively from the centre of the valley into the valley sides. Butler (1959) describes such areas as persistent zones, resting beyond the eroding or sloughing zones. The catchment divide is also at an elevated position ensuring largely aeolian sediments have accumulate during the late Pleistocene erosion-deposition and soil forming cycles. The paleosols in these sections have very high levels of soil development as indicated by the observed pedogenic features (distinct calcans, mangans, coarse highly crystalline calcium carbonate nodules, stress cutans and slicken-sides etc). On the upper and mid slopes well-developed soils may also form. These include *Terra Rossa* and *Redzina* types (dark vertosols) with well expressed calcic subsoil horizons (see P38, P60, P61 and P81, see Appendix 2).

This chapter has also provided verification of field identified pedogenic features such as mangans, calcans, ferrans, and pedogenic nodules. These features display the appropriate chemical signature, either by ESEM analysis or by XRF and XRD. Such features provide evidence of pedogenic development and thus soil and landscape age. Brikeland and others (Birkeland 1988; Gile 1989; Machette *et al.* 1989; Yassoglou *et al.* 1997; Birkeland 1999; Retallack 2003) have provided indications on the likely age of some of the features, in particular well-developed and large pedogenic carbonate nodules. Doyle (1990) has provided some indication of the age of the paleosol and loess deposits using palaeomagnetic dating. Both sets of information suggest the upper parts of the Plio-Pleistocene sediments, which mantle the catchment divide, are of considerable age. Profiles with multiple palaeosols developed in loess have been identified in Serbia (Kostic and Protic 2000), southern Spain (Günster *et al.* 2001), Italy (Busacca and Cremaschi 1998), and also Hungary and the Czech Republic. They demonstrate the paleo-climatic fluctuations which occurred throughout the Pleistocene by the cyclic nature of sedimentary and pedogenic processes. The palaeosols and loess have differing CaCO₃ content, particle size distributions and clay mineralogy. The Pleistocene loess and paleosol sections in the Leipsokouki exhibit similar features and demonstrate an important link between this valley and Middle European and SE European loess-paleosol sequences. Clearly the regular climatic sequences which occurred during the Late Pleistocene extended to the study area. They indicate sedimentation during cooler-drier stadials and soil formation during warmer-wetter interstadials.
Microscope examination has indicated the pedogenic features are well expressed in the older soils and paleosols (mangans, calcans and large precipitated carbonate nodules) but these features are generally absent in the younger soils and pedogenic colluvia. Site CDS4 demonstrates this phenomena very well as the lower profile contained pedogenic material with distinct mangans, thick calcans and clear grooved ped surfaces (evidence of slicken-sides). However the overlying sediment and soil contains only vein carbonate and lacks other pedogenic features.

The limited X-ray diffraction analyses have indicated the catchment divide soils and sediments are dominated by smectite, quartz and calcite with lesser amounts of plagioclase, mica, chlorite and serpentinite. This mineralogy suggests the soils should have high cation exchange capacity and also high total exchangeable bases (Ca$^{2+}$, Mg$^{2+}$, K$,^{+}$, Na$^{+}$). This is supported by the high soil pH values and calcareous nature of many of the soil materials. Doyle (1990) has shown the CEC is $>30$ cmol(+)/kg in P38 and the exchange complex is base saturated. Measurement of soil organic matter of materials thought to be buried soil horizons has shown they do have higher organic carbon values.

This chapter has also shown how most soils and sediments on the mid and upper slopes are deep, fine-textured materials. They provide an abundant source of fine sediment to produce slope wash and pedogenic colluvium. Sediment appears to be transported and mixed by colluvial and slope wash processes with much sediment conducted down slope in depressions or channels and on lower slopes. The slope processes have led to truncation and burial of mature soils as well as the erosion of the entire soil cover on many concave steeper slopes e.g., slopes surrounding C10. Some colluvial transport has been sufficiently gentle and has thus preserved pedogenic features (soil colour, soil structure) of the re-deposited materials. However other examples indicate debris flows are also important modes of transport. Plate 4.25 and Figure 4.16 show a well-developed soil (1 -2 m deep) that has been buried a large debris flow on the upper slopes of the valley.
Plate 4.25 Massive debris flow deposit which buries a well developed soil on the edge of the village of Syndendron. The section occurs at 810 m elevation approximately 250 m from the catchment divide which is at 860 m. The fine textured calcareous materials which comprise the debris flow appear to be derived from Plio-Pleistocene cover-beds on the nearby hilltop.

Figure 4.17 Location and source area debris flow deposit shown above (circle). The arrow shows probable direction of flow. Contours at 4 m intervals.
CHAPTER 5  Syndendron alluvium and associated soils

Introduction
This chapter examines seven stratigraphic sections that contain Syndendron alluvium (C17, C6, C13, C12, C11, C9 and P37). This alluvial sediment was deposited between ca. 14,200 and 11,000 years BP as fans in the upper catchment and as an alluvial terrace in the mid and lower catchment. The alluvium is dominantly fine textured, being composed of inter-beded silts, sand and grits. However a few gravel lenses occur in the gullies of the upper catchment. This alluvium forms the largest and most extensive valley fill.

Site C17 Syndendron alluvium
This site is in the mid catchment 1.9 km west of Mega Sirini and 2.4 km east of Syndendron at latitude 40.11950° N and longitude 21.38930° E (see Figure 5.1). The Syndendron alluvium is exposed in a steep stream cutting and is overlain with a dark alluvial soil. This alluvial soil is buried by three soils forming in pedogenic colluvia. Charcoal was taken from the two lower buried soils and the underlying fine-textured alluvium, 9 m from the top of the section. The alluvium and soils total 14 m in thickness. The charcoal from the alluvium (at 9 m) and the lowest colluvial soil (at 2.1-2.3 m) were radiocarbon dated. The upper-most buried colluvial soil (2.1 – 2.8 m) and the present surface soil contained small (1-3 mm) ceramic fragments (Plate 5.2). Details of soil colour, structure and texture are provided in Table 5.1, additional notes and observations on the materials are provided below and in Plate 5.4.

Comments on the field stratigraphy and microscopy
A1 0 – 0.2 m  Modern topsoil, land surface slopes at 4°. Moderate to strongly developed polyhedral pedality. The peds contain lithic fragments of 2 – 10 mm dia. that are largely sub-angular in shape indicating the material is colluvial. There are also coarse sand sized (<0.5 mm) sub-angular fragments of calcium carbonate, the hard and angular nature (broken) of the carbonate suggests it is colluvial rather than pedogenic. The soil material has a moderate reaction to dilute acid.
B1 0.2 – 1.1 m Modern subsoil has calcium carbonate precipitated on coarse fragments (see Plate 5.4). A few fragments of ceramic material occur in the soil matrix. Sub-angular lithic fragments float in the fine soil matrix indicating the soil is derived from colluvium (note soil sample taken from 0.6-1.1 m).

2A1 1.1 – 1.7 m Buried soil with strong prismatic structure, note prisms are leaning down slope, i.e., the peds appear to be tilted 25° from vertical due to soil creep (see Plate 5.2B). This suggests soil creep may be a key process in the transport of pedogenic colluvial material in this environment. There is soft precipitated calcium carbonate in tubular pores. The peds have a distinct waxy outer surface.

2B1 1.7 – 2.1 m Soil matrix has common lithic fragments (1 – 10 mm) of sub-angular to sub-rounded shape, including some ceramic chips (1 - 2 mm) set in fine silty light clay matrix. These bimodal features suggest the material is colluvial.

3AB 2.1 – 2.3 m Strong pedality with waxy ped surfaces. Few sub-angular to sub-rounded lithic fragments (2 - 10 mm) in finer matrix suggest material is colluvial. Distinct, slightly hardened, calcium carbonate precipitation in tubular pores (former root channels – see Plate 5.4). Fragments of charcoal were sampled and dated at 8,050 ± 110 BP (calibrated age from Wk9923).

3Ck 2.3 – 2.8 m Pale coloured, highly calcareous layer. Carbonate precipitated in many of the tubular pores (see Plate 5.4). Soil matrix contains sub-angular to sub-rounded lithic fragments of 1 – 10 mm. This suggests the material is colluvial.

4A1 2.8 – 3.1 m Buried soil with strong angular pedality with waxy surface and ropey ped fabric, mangans on ped surfaces, soil contains some fragments of charcoal though insufficient for conventional radiocarbon dating. Lack of angular coarse fragments suggests the soil formed on silty clay alluvium.

4BCk 3.1 – 3.3 m Calcareous subsoil with distinct mangans on ped surfaces. Calcium carbonate has precipitated in tubular pores, lack of any
angular or sub-angular fragments suggest the horizon is formed in fine textured alluvium i.e., similar to material below.

4C 3.3 – 14 m  Inter-bedded silts, fine, medium and coarse sands. Beds range from 2-200 mm in thickness. Charcoal sampled from alluvium at 9m from surface and dated at 14,200 ± 1050 cal yr BP (Wk9923).

The three buried topsoils (2A1, 3A1 and 4A1) exhibit the strongest structural development and have slightly heavier textures than their respective subsoils. The buried alluvial soil (2.8 – 3.1 m) has topsoil that is leached of carbonates as indicated by the absence of a reaction to dilute HCl. All the buried topsoils have redder hues (10YR vs. 2.5Y) than their respective BCk and C horizons (see Table 5.1 – moist colour).

Table 5.1  Site C17 field description data

<table>
<thead>
<tr>
<th>Hor</th>
<th>Depth (m)</th>
<th>Description</th>
<th>Field Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev  Ty  Size</th>
<th>HCl React</th>
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<td>2.5Y 2</td>
<td>2 PO 2-5mm</td>
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<td>2.5Y 2</td>
<td>2 PO 2-5mm</td>
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</tr>
<tr>
<td>B1</td>
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<td>ZLC+</td>
<td>10YR 4</td>
<td>1Y 1</td>
<td>3 AB 10-20mm</td>
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<td>2.5Y 4</td>
<td>1Y 1</td>
<td>3 PO 20-50mm</td>
<td>2</td>
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<td>3BCK</td>
<td>3.1-3.3</td>
<td>3rd buried soil, calcareous grading to alluvium</td>
<td>ZLC</td>
<td>2.5Y 4</td>
<td>5Y 6</td>
<td>2 PO 10-20mm</td>
<td>3</td>
</tr>
<tr>
<td>4C</td>
<td>3.3 - 14m sampled at 9 m</td>
<td>Fine textured alluvium, base of section 14,200±1050 BP (calibrated Wk 9923)</td>
<td>FSL</td>
<td>5Y 5</td>
<td>5Y 7</td>
<td>0 SG</td>
<td>4</td>
</tr>
</tbody>
</table>

The topsoils exhibit slightly lower pH values and slightly higher organic carbon content in each of the identified soil profiles (Table 5.2). Calcium oxide is also a little lower in each of the topsoils suggesting leaching and accumulation of organic carbon are the prime causes of lower topsoil pH. Soil pH depth trends follow the increase in calcium carbonate as indicated by both calcite levels (Table 5.4) and reaction to dilute HCl (Table 5.1 and 5.2). The electrical conductivity is highest in the modern soil. Electrical conductivity shows a decreasing trend in each profile. It
Plate 5.1 Site C17 Syndendron terrace with buried alluvial soil capping alluvium. Alluvial soil is buried by two colluvial soils.

Plate 5.2 Close-up of stratification in the fine-textured Syndendron alluvium (A) and close-up of colluvial soil materials with prismatic peds tilted so they lean down slope (dashed line in plate B).
Figure 5.1  Topographic map of site C17 (contour interval is 4 m and gridlines at 500 m)

Plate 5.3 Closer view of the soil layers. Lower dark layer is the buried alluvial soil forming directly on/from the Syndendron alluvium, the darker material above can be separated into two soil materials on morphological characteristics.
Figure 5.2 Radiocarbon calibration curves for site C17a (alluvium) and C17c (colluvial soil materials) after Stuiver et al (1998) and software from Bronk Ramsey (2002).
0 - 0.2 m A1
Mod-strong, fine polyhedral peds (A), common, sub-ang lithic frags (1-10 mm, C) including carbonate lithics (<0.5mm) (insert in B)

0.6 – 1.1 m B1
Mod-strong, fine polyhedral peds, common, sub-ang lithic frags (arrow) including ceramic chips (red fragment insert in B). Carbonate coatings on lithic fragments (C)

1.1 – 1.7 m 2A1
Very strong coarse angular-prismatic pedality (A) with waxy surfaces and carbonate precipitate in tubular pores (B,C)

1.7 – 2.1 m 2B1
Strong coarse angular pedality (A) with waxy surfaces (B), common lithic fragments including ceramic (D, insert), carbonate in tubular pores (B)

Plate 5.4 Micrographs of soil materials from section C17 (scale in mm)
2.1 – 2.3 m 3AB
Roots (A), strong coarse angular pedality (B) with waxy surfaces, slicken-side, common lithic fragments CaCO3 in tubular pores (B, C) dated to 8,085±230 BP using charcoal (C insert)

2.3 – 2.8 m 3Ck
Moderate coarse pedality (A,C), much CaCO3 in tubular pores (B), lithic fragments 2-10mm (C)

2.8 – 3.1 m 4A1
Strong coarse angular pedality (A) with ropey fabric (B), minor CaCO3 in cracks (C), slicken-side, waxy smooth surfaces (A,C), mangans (B)

3.1 – 3.3 m 4BCk
Moderate blocky pedality (A), much carbonate in tubular pores (B), mangans on ped surfaces (C)

at 9 m Alluvium
Inter-bedded sands and silts, few grit layers, bed range 2 – 200 mm thick, orange mottles around pores

Plate 5.4 Micrographs of section C17 (continued)
appears from Tables 5.2 and 5.3 that organic matter accumulation and leaching of calcium (and calcite Table 5.4) are the key pedological changes that occur in these young rendzina type soils.

Table 5.2  Site C17 basic chemical data

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC 1:5 µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.0-0.2</td>
<td>Modern topsoil</td>
<td>3.66</td>
<td>7.5</td>
<td>351</td>
</tr>
<tr>
<td>B1</td>
<td>0.6-1.1</td>
<td>Modern subsoil</td>
<td>1.19</td>
<td>7.8</td>
<td>205</td>
</tr>
<tr>
<td>2A1</td>
<td>1.1-1.7</td>
<td>1st buried soil, topsoil</td>
<td>1.81</td>
<td>8.0</td>
<td>175</td>
</tr>
<tr>
<td>2AB</td>
<td>1.7-2.1</td>
<td>1st buried soil, subsoil</td>
<td>0.57</td>
<td>8.1</td>
<td>158</td>
</tr>
<tr>
<td>3AB</td>
<td>2.1-2.3</td>
<td>1st buried soil, subsoil</td>
<td>0.59</td>
<td>8.2</td>
<td>153</td>
</tr>
<tr>
<td>3Ck</td>
<td>2.3-2.8</td>
<td>Charcoal date 8,085+230 BP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4A1</td>
<td>2.8-3.1</td>
<td>2nd buried soil on alluvium</td>
<td>0.58</td>
<td>8.0</td>
<td>140</td>
</tr>
<tr>
<td>4BCk</td>
<td>3.1-3.3</td>
<td>2nd buried soil, calcareous grading to alluvium</td>
<td>0.58</td>
<td>8.4</td>
<td>132</td>
</tr>
<tr>
<td>4C</td>
<td>3.3 - 14</td>
<td>Fine textured alluvium, base of section (14,200 ± 1050 BP)</td>
<td>0.23</td>
<td>8.5</td>
<td>157</td>
</tr>
</tbody>
</table>

XRF and XRD analysis of samples

The X-ray fluorescence data help support the field separation of the upper section into four separate soil profiles. The resistant oxides TiO$_2$ and K$_2$O increase abruptly from the base of one soil to the top of the next. Titanium oxide is an important constituent in the resistant detrital minerals such as ilmenite and rutile (Read 1947), while potassium is found in the weathering resistant K-feldspars. Calcium has been leached from all the buried topsoil horizons and has accumulated in the lower horizons in each case. It appears calcium is the element most affected by pedogenic processes and this is demonstrated in the increasing calcite trend shown in Table 5.4. The resistant oxides SiO$_2$, TiO$_2$ and K$_2$O all peak in the buried alluvial topsoil (4A1), suggesting it is either highly weathered or of different parent material from the soils above. The absence of sub-angular poorly sorted lithic fragments supports the notion it is of alluvial rather than colluvial origin. The higher mica and quartz content may go some way toward explaining the higher SiO$_2$, TiO$_2$ and K$_2$O values of the 4A1. It also has high iron oxide levels. The higher manganese in the 4A1 is supported by the presence of mangans on the ped surfaces.
Table 5.3 Major elemental oxides (%) by x-ray fluorescence for site C17

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Depth (m)</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0-0.2</td>
<td>34.57</td>
<td>0.30</td>
<td>5.88</td>
<td>6.02</td>
<td>0.09</td>
<td>12.29</td>
<td>15.61</td>
<td>0.47</td>
<td>0.94</td>
<td>0.12</td>
<td>23.55</td>
<td>99.82</td>
</tr>
<tr>
<td>B1</td>
<td>0.6-0.11</td>
<td>36.92</td>
<td>0.35</td>
<td>6.76</td>
<td>6.79</td>
<td>0.10</td>
<td>11.47</td>
<td>15.57</td>
<td>0.48</td>
<td>0.99</td>
<td>0.09</td>
<td>19.87</td>
<td>99.39</td>
</tr>
<tr>
<td>2A1</td>
<td>1.1-1.7</td>
<td>44.90</td>
<td>0.43</td>
<td>8.42</td>
<td>8.10</td>
<td>0.12</td>
<td>11.54</td>
<td>9.65</td>
<td>0.58</td>
<td>1.20</td>
<td>0.08</td>
<td>14.45</td>
<td>99.47</td>
</tr>
<tr>
<td>2B1</td>
<td>1.7-2.1</td>
<td>44.11</td>
<td>0.42</td>
<td>8.36</td>
<td>7.65</td>
<td>0.11</td>
<td>10.65</td>
<td>11.24</td>
<td>0.67</td>
<td>1.21</td>
<td>0.08</td>
<td>14.98</td>
<td>99.48</td>
</tr>
<tr>
<td>3AB</td>
<td>2.1-2.3</td>
<td>49.08</td>
<td>0.49</td>
<td>10.06</td>
<td>6.62</td>
<td>0.10</td>
<td>8.07</td>
<td>9.46</td>
<td>1.25</td>
<td>1.79</td>
<td>0.11</td>
<td>12.29</td>
<td>99.32</td>
</tr>
<tr>
<td>3Ck</td>
<td>2.3-2.8</td>
<td>40.60</td>
<td>0.41</td>
<td>8.28</td>
<td>5.23</td>
<td>0.07</td>
<td>7.55</td>
<td>16.99</td>
<td>1.27</td>
<td>1.57</td>
<td>0.12</td>
<td>17.74</td>
<td>99.83</td>
</tr>
<tr>
<td>4A1</td>
<td>2.8-3.1</td>
<td>52.44</td>
<td>0.61</td>
<td>14.00</td>
<td>9.66</td>
<td>0.13</td>
<td>9.52</td>
<td>1.93</td>
<td>0.81</td>
<td>2.66</td>
<td>0.07</td>
<td>7.84</td>
<td>99.67</td>
</tr>
<tr>
<td>4BCk</td>
<td>3.0-3.2</td>
<td>37.06</td>
<td>0.44</td>
<td>10.14</td>
<td>6.89</td>
<td>0.08</td>
<td>7.87</td>
<td>16.23</td>
<td>0.80</td>
<td>1.94</td>
<td>0.12</td>
<td>17.96</td>
<td>99.53</td>
</tr>
<tr>
<td>4C</td>
<td>9 m</td>
<td>36.78</td>
<td>0.35</td>
<td>6.51</td>
<td>4.19</td>
<td>0.06</td>
<td>8.70</td>
<td>19.62</td>
<td>1.11</td>
<td>1.25</td>
<td>0.11</td>
<td>21.32</td>
<td>100.01</td>
</tr>
</tbody>
</table>

The whole profile is dominated by the clay mineral smectite, with the exception of the underlying alluvium where smectite and calcite are co-dominant (Table 5.4). K-feldspar, serpentine and dolomite are more abundant in the upper colluvial part of the section (0 - 2.8 m) while smectite is higher in the 4A1 and 4BCk of the alluvial soil. The low calcite and dolomite levels in the buried alluvial soil suggest it may have undergone the longest period of leaching and soil development in the section.

Table 5.4 X-ray diffraction data for site C17

<table>
<thead>
<tr>
<th>Hor</th>
<th>Depth (m)</th>
<th>35-50%</th>
<th>25-35%</th>
<th>15-25%</th>
<th>10-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0-0.2</td>
<td>Smec.</td>
<td>Calcite</td>
<td>Serpentine</td>
<td>Qtz, Dolm</td>
<td>Mica, Chl., Plag.</td>
<td>K-Feld.</td>
<td>Talc</td>
</tr>
<tr>
<td></td>
<td>0.6-1.1</td>
<td>Smec.</td>
<td>Calcite</td>
<td>Serpentine</td>
<td>Quartz, Chl</td>
<td>Dolm., Mica, Plag.</td>
<td>K-Feld. Talc</td>
<td></td>
</tr>
<tr>
<td>2B1</td>
<td>1.7-2.1</td>
<td>Smec.</td>
<td>Calcite</td>
<td>Serpentine</td>
<td>Quartz</td>
<td>Plag., Chl., Mica, Dolo.</td>
<td>K-Feld., Talc</td>
<td></td>
</tr>
<tr>
<td>3Ck</td>
<td>2.3-2.8</td>
<td>Smec.</td>
<td>Calcite</td>
<td>Quartz, Mica</td>
<td>K-Feld., Dolo.</td>
<td>K-Feld., Dolo.</td>
<td>Talc</td>
<td></td>
</tr>
<tr>
<td>4C</td>
<td>9 m</td>
<td>Cal.,</td>
<td>Mica, Qtz, Serp.</td>
<td>Cal.,</td>
<td>Mica, Qtz, Serp.</td>
<td>Plag., Chl., Dolo.</td>
<td>K-Feldspar</td>
<td>Tal</td>
</tr>
</tbody>
</table>

Chronology
Charcoal taken from the alluvium at 9 m from the surface has provided a date of 11,794 ± 199 BP (Wk 9923) which is calibrated to 14,200 ± 1,050 cal yrs BP. This
sample is 5 m above the base of the section and suggests the alluvial deposition was well underway prior to the start of the Holocene. There was insufficient charcoal in the alluvial soil for conventional dating. However, dating of an overlying colluvial soil (3AB) at 2.1-2.3 m gave a calibrated date of 8,095 ± 110 cal yr BP (see Figure 5.2, Wk9923). This colluvial soil is less well developed than the alluvial soil it buries, which is leached of all dolomite and most calcite. Thus the date probably indicates close to when burial of the alluvial soil occurred. If this interpretation is correct, it suggests leaching of calcite from levels of 15-25% to less than 2% takes less than 6,000 years in the late Pleistocene to early Holocene environment (Table 5.4). The charcoal at 2.1 – 2.3 m also hints at landscape disturbance and associated soil movement on the surrounding slopes after a period of relative stability prior to 8,095 cal yrs BP. This stable period is most likely to have occurred during the early Holocene when conditions were moister and oak forest was expanding and covering the region (Wijmstra 1969; Turner and Greig 1975; Willis 1992a; Tzedakis 1993; Turner and Sanchez-Goni 1997; Willis 1997).

**Summary**

At section C17 fine textured alluvium was laid down in a series of fine beds to a total thickness of 11 m. The source of this fine material is likely to be the mid and upper slopes of the valley where deep fine textured soil materials are known to occur and there is evidence of fine-textured debris flows, colluvium and slope wash (see Chapter 4). Other sites presented in this chapter will provide dating to confirm the timing of the transport of this sediment down the slopes of the valley floor (C6, C13 and C19). Charcoal within the alluvium indicates fires were occurring in the catchment after ca. 14 kyr BP. The charcoal in the alluvium indicates an age close to but younger than 14 kyr BP for the commencement of the Syndendron alluvium and its deposition was completed well before 8 kyr BP and more likely prior to 10 kyr BP.

Following the alluvial deposition a moderately well developed soil formed on the deposit. Leaching removed much calcite and all the dolomite in the thin topsoil. At about 8 kyr BP this alluvial soil was buried by a pedogenic colluvium and charcoal in this material indicates fires were occurring in the catchment. A shorter period of soil leaching occurs as the calcite is reduced to 9% from levels of 15-25%, which are typical of recently deposited soil colluvium (eg the modern A1 and B1 at 0 – 1.1 m).
This “soil” was later capped by more soil-like colluvium which underwent a similar leaching cycle. Then the section was recently buried by 1.1 m of soil colluvium which, from the data presented, appears un-leached (see CaO in Table 5.3 and calcite in Table 5.4). The only pedogenic characteristic it exhibits is an accumulation of organic matter at the surface (Table 5.2).

**Site C6 Paleosol buried by Syndendron alluvium and debris flow deposits**

This section is exposed in a stream cutting below the important archaeological site of Paleokastro, 1.5 km NE of Syndendron (latitude 40.1324 N and longitude 21.3664 E, see Figure 5.2). Charcoal was collected from the 2A1 horizon of a paleosol buried by alluvium and debris flow deposits for radiocarbon dating. The paleosol topsoil was dated at $12,404 \pm 292$ $^{14}$C yr BP or $14,750\pm 1000$ cal yr BP when calibrated (see Figure 5.4, Wk 9816). This buried, dark brown paleosol forms on a slope (see Plate 5.5) descending the former valley side. The paleosol topsoil and subsoil were very hard when dry and massive when wet. The paleosol exhibited distinct angular blocky and prismatic structure when dry and prominent orange mottles occurred along root channels in the A and B-horizons. The abundance of mottles increased in the lower slope position. Details of soil colours, structure and texture are provided in Table 5.5, additional notes and observations on the materials are provided below and in micrographs in Plate 5.6.

**Field stratigraphy** (zero was taken at top of paleosol for simplicity)

- **9 m above streambed**: The modern soil surface is approximately 9 m above the modern stream bed. The modern soil was not sampled.
- **Alluvium/debris**: Inter-beded silts and sands, alluvium- well stratified and over 3 m of visible exposure. On left-hand side of exposure a debris flow deposit rests against the alluvium, it contains angular boulders and stones (see Plate 5.5). Sample taken of alluvial component for analysis given in Tables 5.5 – 5.8.
- **0 – 0.15 m 2A1**: Dark grey paleosol topsoil with sloping surface ranging from 3-4° in left of section and rising up to 12-18° degrees in the right-hand part of the section. The soil is hard when dry with moderate block pedality and some orange mottling. There are common weathered lithic fragments along with many
fragments of charcoal in the silty light clay matrix. Samples of charcoal provide a date of 14,750 ± 1000 cal yr BP (WK9816).

0.1 – 0.55 m  2B2  Dark greyish brown subsoil horizon of buried soil which is highly mottled in the lower lying part of the section but becomes less mottled as the paleosol slopes up to the right-hand part of the section. In the lower lying part of the section the subsoil is very hard when dry and has a prismatic structure. Fine salt crystals could be seen on the dry ped surface and the electrical conductivity is the highest (900 uS/cm) of any soil in the catchment.

0.55 – 1.5 m  2Ck  Pale olive, less compact, calcareous sediment with sub-angular lithic fragments (2-12 mm) set in silty light clay matrix suggesting it is a slope deposit (Plate 5.7 - 5.8).

This paleosol appears to be derived from colluvium as indicated by the fragments of mudstone and charcoal, which float in the finer soil matrix (see Plate 5.8). The soil structure is well expressed in the buried soil when dry, but the soil becomes massive when wet due to swelling of smectite clay present (Plate 5.5 vs. Plate 5.8 and Table 5.8). The paleosol field textures are heavier than the overlying alluvial materials. The paleosol has salt crystals on the exposure surface suggesting slightly saline seepage occurs at the site following sufficient rainfall. This is confirmed by the high electrical conductivity of the 2B2, the highest in the study area (Table 5.6).

Table 5.5  Field morphology data for site C6

<table>
<thead>
<tr>
<th>Hor (m)</th>
<th>Depth (m)</th>
<th>Field Description</th>
<th>Field Text.</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0-0.15</td>
<td>Overlying Stratified fine alluvium &amp; debris flow deposits</td>
<td>CLFS</td>
<td>5Y 5 3</td>
<td>5Y 6 3 0</td>
<td>SG 2</td>
<td>3</td>
</tr>
<tr>
<td>2A1</td>
<td>0.15-0.55</td>
<td>Paleosol = 14,750 ± 1000 cal yr BP (calibrated WK9816)</td>
<td>Hu ZLC</td>
<td>2.5Y 4 1</td>
<td>2.5Y 4 1 2</td>
<td>AB 50-100mm 1</td>
<td>1</td>
</tr>
<tr>
<td>2B2</td>
<td>0.55-1.5</td>
<td>Paleosol subsoil</td>
<td>ZLC</td>
<td>4Y 4 2</td>
<td>5Y 7 3 3</td>
<td>PR 20-50mm 1</td>
<td>1</td>
</tr>
<tr>
<td>2Ck</td>
<td>1.5</td>
<td>Calcareous lower subsoil</td>
<td>ZLC-</td>
<td>5Y 6 3</td>
<td>5Y 7 2 0</td>
<td>SG 2</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5.6 shows the soil pH increases with depth in the buried profile while the level of organic carbon decreases. Most of the calcium carbonates have been leached from the topsoils and upper subsoil, as shown by the weak reaction to dilute HCl and the
Plate 5.5 Site C6 Sloping paleosol buried by Syndendron alluvium. Stratified sandy and silty alluvium can be seen capping a sloping buried soil dated at 14,750 ± 1000 years BP (WK9816 calibrated date). The modern stream has now incised to a bedrock base (A). In B and C below the stratified alluvium can be seen overlying the buried soil in the right-hand part of the frames but this is inter-fingered with debris flow deposits clearly shown in the left portion of both frames (note large boulders).
Plate 5.6 View of sites C6 and C9 in Syndendron alluvium and C16 younger slope deposits and Sirini alluvium.

Figure 5.3 Approximate outline of the Syndendron fan alluvium indicated with dashed line. (4 m contour intervals). Note the Syndendron alluvium extends into the side valleys indicating the ultimate source of the sediment, the steep back-slopes which rise-up to the flatter ridge tops and drainage divide (such as Paleokastro an important archaeological site since the Neolithic).
Figure 5.4 Radiocarbon calibration curves for sites C6a and C13 after Stuiver et al (1998) and software from Bronk Ramsey (2002).
Alluvium
capping buried soil profile (below), note strong rounding and well sorted nature of sediment

2A1 horizon
hard peds with fragmentary charcoal (C), lithics (1-5 mm, B), few orange mottles (A)

2B2 horizon
Strong prismatic pedality, orange mottling along pores and root channels, angular lithic fragments in matrix (B arrows), soft calcium carbonate deposited along pores

2Ck horizon
Moderate angular pedality, calcium carbonate deposited along pores (A) and channels, angular lithic fragments (B arrow) in finer matrix.

Plate 5.7 Section C6 Buried soil layer dated to 14,750 ± 1000 BP (calibrated date Wk9816, scale in mm).
Plate 5.8 Close-up view of paleosol at C6 which is buried and dated at 14,750 ± 1000 BP (WK9816 calibrated). Stratified fine-textured alluvium can be seen in the right-hand part of plate A but this is inter-fingered with debris flow deposits visible in the left portion of plate A. Both materials abruptly overlie the paleosol. The paleosol contains lithic fragments (A and B arrows) indicating it is colluvial. The burial of the soil by debris flow deposits and alluvium suggest sudden landslide instability after about 15 Ka BP.
low calcite levels (see Table 5.5 and 5.7). A moderate salinity level occurs in the buried paleosol.

### Table 5.6 Basic chemical properties of site C6

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Depth (m)</th>
<th>Description</th>
<th>Organic Carbon (%)</th>
<th>pH Water 1:5</th>
<th>EC µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Overlying</td>
<td>Alluvium &amp; debris flow deposits</td>
<td>0.17</td>
<td>8.2</td>
<td>442</td>
</tr>
<tr>
<td>2A1</td>
<td>0-0.15</td>
<td>Paleosol topsoil</td>
<td>1.04</td>
<td>7.7</td>
<td>610</td>
</tr>
<tr>
<td>2B2</td>
<td>0.15-0.55</td>
<td>Paleosol subsoil</td>
<td>0.44</td>
<td>7.9</td>
<td>905</td>
</tr>
<tr>
<td>2Ck</td>
<td>0.55-1.5</td>
<td>Paleosol calcic subsoil</td>
<td>0.22</td>
<td>8.6</td>
<td>245</td>
</tr>
</tbody>
</table>

### XRD and XRD analysis of samples

The X-ray fluorescence data highlight the leaching in the buried paleosol as calcium oxide increases with depth 2A1 – 2Ck, while almost all other oxides decrease (Table 5.7 and Graph 5.1). The exceptions are sodium, manganese and phosphorus which all have relatively static depth trends. The XRF “loss” percentages also increases with depth reflecting the carbonate and water associated with the calcium oxide. The buried profile exhibits higher silica, aluminium and iron oxide contents in the topsoil than the overlying alluvium and these values decrease down the buried profile. The biggest changes occur in silica and calcium oxides.

### Table 5.7 Major elemental oxides (%) by x-ray fluorescence for site C6

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Depth (m)</th>
<th>SiO$_2$</th>
<th>TiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>Fe$_2$O$_3$</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>P$_2$O$_5$</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>All.</td>
<td>Overbur.</td>
<td>36.78</td>
<td>0.36</td>
<td>6.74</td>
<td>4.54</td>
<td>0.06</td>
<td>9.23</td>
<td>19.03</td>
<td>0.98</td>
<td>1.35</td>
<td>0.11</td>
<td>20.43</td>
<td>99.61</td>
</tr>
<tr>
<td>2A1</td>
<td>0-0.15</td>
<td>53.66</td>
<td>0.54</td>
<td>10.48</td>
<td>8.24</td>
<td>0.05</td>
<td>12.34</td>
<td>1.86</td>
<td>0.95</td>
<td>1.85</td>
<td>0.08</td>
<td>9.42</td>
<td>99.48</td>
</tr>
<tr>
<td>2B</td>
<td>0.15-0.55</td>
<td>47.54</td>
<td>0.46</td>
<td>9.11</td>
<td>7.17</td>
<td>0.08</td>
<td>11.97</td>
<td>8.07</td>
<td>0.90</td>
<td>1.64</td>
<td>0.10</td>
<td>12.89</td>
<td>99.93</td>
</tr>
<tr>
<td>2Ck</td>
<td>0.55-1.5</td>
<td>37.51</td>
<td>0.38</td>
<td>7.36</td>
<td>4.64</td>
<td>0.08</td>
<td>7.16</td>
<td>19.91</td>
<td>0.94</td>
<td>1.35</td>
<td>0.10</td>
<td>20.91</td>
<td>100.34</td>
</tr>
</tbody>
</table>

The X-ray diffraction analyses of the paleosol show it is dominated by the clay mineral smectite, particularly in the upper part. The minerals quartz and serpentine are also higher in the topsoil. The carbonate minerals dolomite and calcite have been largely leached from the upper profile. Calcite reaches 15-25% in the 2Ck horizon. Magnesium oxide is highest in the upper paleosol and decreases with depth despite the leaching of dolomite. This indicates the magnesiuim is associated with the higher smectite and serpentine in the upper part of the paleosol.
Table 5.8  X-ray diffraction data for site C6

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Depth m</th>
<th>35.50%</th>
<th>25-35%</th>
<th>15-25%</th>
<th>10%-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Ck</td>
<td>0.55-1.5</td>
<td>Smec.</td>
<td>Cal.</td>
<td>Mica</td>
<td>Qtz, Chl., Serp., Plag.</td>
<td>Talc</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chronology
Charcoal taken from the 2A1 of the buried paleosol gave an age of 14,750 ± 1,000 cal yr BP (Wk9821). The abundance of charcoal in the buried soil suggests significant fires occurred in the catchment after about 14.7 kyr BP and that these are associated with the deposition of a colluvial paleosol. This paleosol was then buried by alluvium and debris flow materials. The contact between the charcoal rich paleosol and the overlying alluvium can be traced upslope to site C9 (see Plate 5.5). At C9 the Syndendron alluvium is capped by a soil dated to 8 cal kyr BP. The C6 site indicates fire is a likely agent in catchment disturbance as the charcoal rich paleosol is subsequently buried by debris flows and alluvium. The alluvium appears to dip down slope suggesting its source is slope wash from the valley sides.

Discussion and interpretation
A paleosol has developed on slope deposits/colluvium on a hill slope that descends to near the level of the present valley floor (1-2 m higher). This soil underwent leaching of calcite and dolomite and the accumulation of organic carbon. Mottling occurred in the wetter lower lying landscape positions. Dating at site C17 has suggested such soil leaching can occur in less than 6,000 years of stable soil forming conditions. Macroscopic charcoal incorporated in the topsoil of the paleosol indicates fires were occurring in the landscape after ca 14.7 cal kyr BP. Whether the fires which produced the charcoal led to slope destabilisation is not known. However the mixing of the fragments of charcoal in the topsoil suggests at least soil creep did occur. Sometime after this debris flows transported angular stones and boulders in a silty matrix burying the charcoal bearing paleosol. The debris flows and other slope wash resulted in associated alluvial aggradation down stream (e.g., C17). This is supported by the fact the poorly sorted material containing boulders of mudstone are inter-fingered with the finer alluvium, indicating they are contemporary facies. The boulder nature of the debris flow deposit suggest it must have been sourced from the
hill slopes on the western side of the tributary stream while the gentler eastern slopes could provide slope wash alluvium (see Figure 5.3). This is supported by the orientation of sediment in the section with the debris flow deposits to the western side of the section. The cause of the hill slope instability is not known but a fire could quickly spread up the gully and cause temporary loss of soil cover on the valley sides. The fine textured loess mantles on the slopes above the site could then be easily transported to the lower parts of the landscape by slope wash. The direct cause of catchment fires after about 15 cal kyr BP cannot be determined but it seems humans were in this area at the time (Wilkie and Savina 1992) as a Palaeolithic tool has been found at Syndendron, 1.5 km to the southwest of the site.

The facies depositional sequence at the site is as follows (codes are outlined in Chapter 3):- CO-SO-OB+DF-SO-IN.

**Site C13 Paleosol buried by slope wash**

Site C13 is located 1.8 km NE of Syndendron at latitude 40.13333° and longitude 21.3675° (see Figure 5.5). A 150 m long hill slope exposure provides evidence of a buried paleosol capped by an ash layer indicating a major fire in this part of the catchment at 12,250 ± 700 cal yr BP (see Figure 5.4, Wk9821). The fire was followed by slope wash and burial of the pre-existing soil surface with 2-2.5 m of fine textured alluvial sediment. The paleosol formed on the valley side where slope angles are typically 12° to 14° but in some parts are up to 20°. The paleosol is moderately thick (1.5 m) and has a strong angular blocky structure. The fine textured (sandy and silty) alluvial slope wash deposited above the paleosol is on a shallower slope angle than the land surface i.e., 5-6° vs. 12-14°. The paleosol appears to have formed from slope deposits as the silty clay matrix contains sub-angular fragments of mudstone and fine-grained sandstone. In the higher (up slope) parts of the section the paleosol overlies steeply dipping inter-beded Tertiary mudstone and fine sandstone. In the lower parts of the slope, the profile appears to be underlain by inter-beded (10-20 cm thick) gritty and fine textured alluvium dipping at approximately 6-8°. Perhaps a prior slope wash deposit. Details of material morphology including soil colour, structure and texture are provided in Table 5.9. Additional notes and observations on the materials are provided below and in micrographs in Plate 5.10.
Field stratigraphy and sample details

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 2 m</td>
<td>C</td>
<td>Fine sandy and silty bedded sediment, deposited on a dip of 5-6°, some fine gravel layers, layering and sorting suggest material is slope wash alluvium.</td>
</tr>
<tr>
<td>2 – 2.1 m</td>
<td>2AC</td>
<td>Ashy material, of low bulk density, with mixed charcoal pieces dated at 12,250 ± 700 cal yr BP (Wk9821).</td>
</tr>
<tr>
<td>2.1 – 2.25 m</td>
<td>3A1</td>
<td>Topsoil of paleosol with sub-angular lithic fragments (2 – 10 mm) in finer soil matrix, compact, dark colour indicates humus accumulation, lithic fragments suggest material is colluvial.</td>
</tr>
<tr>
<td>2.25 – 3.0 m</td>
<td>3B2</td>
<td>Blocky structured soil contains lithic fragments of mudstone floating in matrix indicating colluvial origin, common distinct orange mottles down root channels.</td>
</tr>
<tr>
<td>3.0 – 4.5 m</td>
<td>3BCk</td>
<td>Matrix contains some angular sandstone fragments that suggest the material is colluvial, they also contain 20 - 30 mm diameter nodules of calcium carbonate. However they do not appear to have formed in situ. Prominent orange mottles occur along root channels profile on the lower slopes.</td>
</tr>
<tr>
<td>4.5 - 5 m</td>
<td>3Ck</td>
<td>As above but with calcium carbonate precipitated along tubular pores (old root channels). In some parts of the exposure this capped fine textured alluvium with fine gravelly alluvial layers derived from mudstone. This alluvium has bedded (5-20 cm thick) and dips at 7° toward the stream i.e., an older slope wash deposit.</td>
</tr>
</tbody>
</table>

The depositional sequence at site C13 is thus IN-SW-CO-SO-SW.

In the lower part of this exposure an unusual, loose, orange, gritty material appeared to be inset into the topsoil horizon (see Plate 5.11-A). This material gave high iron and oxygen peaks using environmental scanning electron microscope (ESEM) in backscatter electron analysis mode (Figure 5.6). Using ESEM micrographs and standard microscopy the fragments were identified as angiosperms (Jordon 2003). The ferruginised fragments from 3A1 horizon exhibited features such as tracheid, vessels, parenchyma (as seen in angiosperms), pits on vessel walls and wood fibres (see Plate 5.13) (Jordon 2003). Another type of iron oxide fossilised plant material was located on the eroded soil surface above the site. This material has leaf, stem and...
Plate 5.9 Site C13 Photograph A shows the sloping paleosol exposed by stream undercutting. The paleosol is buried by pale coloured slope wash. Photograph B shows close view of the paleosol, charcoal taken from above the 3A1, in 2AC, is dated at 12,250 ± 700 years BP (Wk9821). Note orange mottles along root channels in 3B2 and 2BC. The buried paleosol is developed in slope deposits, as indicated by sub-angular fragments, these overlie alluvial deposit.
Figure 5.5 Topography at site C13 and proximity to site C6 (contour interval 4 m)
0 – 2 m  C
Well sorted and bedded slope wash material overlying buried soil profile

2.0 – 2.1 m  2AC
Loose ashy and charcoal rich layer over paleosol with lithic fragments and fragments of calcium carbonate, highly calcareous, loose. Dated to 12,250±700 BP

2.1 – 2.25 m  3A1
Moderate pedality, silty clay with 2 – 10 mm sub-angular lithic fragments (A, B) and charcoal (A)

2.25 – 3.0 m  3B2
Moderate blocky pedality, sub-angular lithic and carbonate fragments (1-10 mm, A) and iron mottling along root channels (B)

3.0 – 4.5 m  3BC
Matrix has sub-angular lithic fragments and calcium carbonate deposited along in root channels (B)

4.5 – 5m+  3Ck
Sub-angular lithic fragments (2 -20 mm) in finer matrix, much calcium carbonate deposited along root channels (colluvium)

Plate 5.10 Micrographs of soil materials from section C13 (scale in mm)
Plate 5.11 Site C13 showing a close-up of the upper part of the sloping buried paleosol. The distinct wedge of orange material appears inset into paleosol topsoil. This material is ferruginised wood flakes – it may be anthropogenic. Plate below shows the topsoil, which contains much charcoal dated at 12,250 ± 700 BP (calibrated Wk9821).
Plate 5.12  Section C13 sample from 3A1 horizon, micrographs A-F show fragmentary wood material identified as angiosperm (Dr Greg Jordan pers comm) replaced by iron oxide. Micrographs G - I show fragments of leaves and plant stems (grasses, monocots, salix or pussy willow, Dr Dennis Morris pers comm.) set in calcium carbonate. These were located on the modern soil surface, derived from erosion of the C13 paleosol further upslope (scale in mm).
Plate 5.13 Environmental scanning electron micrographs of fragments from 3A1 horizon of buried soil. – identified as wood fragments, showing tracheid (b, d), vessels (a, c) and parenchyma as in hardwoods (angiosperms), pits on vessel walls (c) and wood fibre (e, f) and pores in matrix material (g). Plant material has been replaced by iron oxide. Plant fragments identified by Dr Greg Jordon pers comm 2003.
Figure 5.6  Semi-quantitative analysis using ESEM spectra of ferruginised wood fragments from 3A1 horizon of site C13, fragment is the one shown in Plate 5.12-A. Graph a) shows very high iron oxide which has probably replaced the plant tissue, graph b) shows higher Si, Al, Mg and K and probably represents a clay mineral such as mica and/or smectite while graph c) has significant sodium, typical of feldspars.
Figure 5.7 ESEM data of the surface of plant leaf trace fossils found scattered on the modern soil surface at site C13. Images a) and b) show the crystalline surface of the matrix material in which the trace fossils are preserved. Platy minerals can be seen in image b) probably mica as indicated by graph d). However the bulk of the crystalline matrix in a) is composed of calcium carbonate as indicated by graph c) which has high O, Ca and moderate C levels. Smectite or even talc may be represented as indicated by moderate Mg and Si. However despite iron oxide appearance, matrix is low in this element suggesting the iron is only present as a coating.
grass impressions set in a hard iron oxide material (see Plate 5.13). The leaf impressions were identified as some form of willow (*Salix sp*) and grasses (Morris and Baker 2004). Given this plant material was sourced from above the site indicates it has been washed down from the slope above the site. Perhaps a spring provided sufficient moisture for willows to grow on the slopes above the site.

### Table 5.9  Field morphology data for section C13

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Horizon/sample type</th>
<th>Field Text.</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Soil Structure</th>
<th>React HCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0–2</td>
<td>Slope wash alluvium</td>
<td>FSL+</td>
<td>7.5Y 4 6</td>
<td>7.5Y 6 8</td>
<td>0 SG</td>
<td>3</td>
</tr>
<tr>
<td>2AC</td>
<td>2-2.1</td>
<td>Ash layer associated with sloping Paleosols</td>
<td>L</td>
<td>2.5Y 5 3</td>
<td>2.5Y 5 2</td>
<td>0 SG</td>
<td>4</td>
</tr>
<tr>
<td>3A1</td>
<td>2.1-2.25</td>
<td>Topsoil of paleosols</td>
<td>ZLC</td>
<td>2.5Y 3 2</td>
<td>2.5Y 5 2</td>
<td>2 PO 20-50mm</td>
<td>2</td>
</tr>
<tr>
<td>3B2</td>
<td>2.25-3.0</td>
<td>Subsoil of paleosol</td>
<td>ZLC-</td>
<td>2.5Y 5 3</td>
<td>2.5Y 7 4</td>
<td>1 AB 20-50mm</td>
<td>3</td>
</tr>
<tr>
<td>3BCk</td>
<td>3.0-4.5</td>
<td>Lower subsoil paleosol</td>
<td>ZLC</td>
<td>4Y 5 3</td>
<td>5Y 6 3</td>
<td>1 SB 10-20mm</td>
<td>3</td>
</tr>
<tr>
<td>3Ck</td>
<td>4.5-5+</td>
<td>Colluvial slope deposits below soil</td>
<td>ZLC-</td>
<td>5Y 5 3</td>
<td>5Y 6 3</td>
<td>1 AB 20-50mm</td>
<td>4</td>
</tr>
</tbody>
</table>

### Basic soil chemical properties

The buried paleosol (2.1 – 5m) at C13 has an increasing pH trend with depth and decreasing organic carbon trend. The organic matter and leaching of carbonate probably explain the profile pH trend. However, the ashy layer (2AC) has the highest organic carbon levels but also high pH. The higher carbon probably relates to the ash in the layer while the pH remains high due the high calcium carbonate levels (HCl reaction of class 4). The overlying slope wash (C horizon) and paleosol subsoil have the lowest organic carbon levels. The electrical conductivity (EC) is highest in the 3A1 and this may be due to leaching of salts from the ash layer and their accumulation in the finer textured paleosol topsoil, EC then deceases with depth.

### Table 5.10  Basic chemical properties of site C13

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC μS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0-2</td>
<td>Slope wash alluvium</td>
<td>0.31</td>
<td>7.9</td>
<td>160</td>
</tr>
<tr>
<td>2AC</td>
<td>2-2.1</td>
<td>Ash layer associated with sloping paleosols</td>
<td>1.63</td>
<td>8.2</td>
<td>145</td>
</tr>
<tr>
<td>3A1</td>
<td>2.1-2.25</td>
<td>Topsoil of paleosols</td>
<td>0.68</td>
<td>7.9</td>
<td>325</td>
</tr>
<tr>
<td>3B2</td>
<td>2.25-3.0</td>
<td>Subsoil of paleosols</td>
<td>0.31</td>
<td>8.0</td>
<td>124</td>
</tr>
<tr>
<td>3BCk</td>
<td>3.0-4.5</td>
<td>Lower subsoil paleosol</td>
<td>0.28</td>
<td>8.2</td>
<td>147</td>
</tr>
<tr>
<td>3Ck</td>
<td>4.5-5+</td>
<td>Colluvial slope deposits below soil</td>
<td>0.28</td>
<td>8.2</td>
<td>109</td>
</tr>
</tbody>
</table>
XRF and XRD analysis of samples

Key features of the X-ray fluorescence data are the high calcium oxide levels in the overlying alluvium and very high calcium oxide levels in the ash layer. Calcium oxide is leached out of the 3A1 and accumulates in the 3B2 and 3BC horizons. The more resistant elements SiO2, K2O and TiO2 are highest in the 3A1 and decrease in the 3B2 and 3BC. The high K2O is probably related to the higher K-feldspar, as mica is constant down the profile. The higher SiO2 no doubt relates to the higher quartz levels in the 3A1. Iron and aluminium oxides are much lower in the ashy layer and the covering slope wash but nearly double in the paleosol they bury. The high iron and aluminium in the paleosol relates to the higher smectite levels, while the low levels in the ash layer reflect the high calcium carbonate content of the ash and its lower clay content (loam field texture). The high magnesium oxide in the whole profile, with the exception of the ashy layer, relates to the moderate amount of magnesium bearing minerals serpentine, smectite and dolomite.

Table 5.11 Major elemental oxides (%) by X-ray fluorescence for site C13

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (m)</th>
<th>SiO2</th>
<th>TiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na2O</th>
<th>K2O</th>
<th>P2O5</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 0–2</td>
<td></td>
<td>32.81</td>
<td>0.27</td>
<td>5.34</td>
<td>4.93</td>
<td>0.07</td>
<td>10.77</td>
<td>20.83</td>
<td>0.67</td>
<td>0.88</td>
<td>0.10</td>
<td>23.10</td>
<td>99.77</td>
</tr>
<tr>
<td>2AC 2-2.1</td>
<td></td>
<td>17.10</td>
<td>0.18</td>
<td>3.61</td>
<td>4.64</td>
<td>0.05</td>
<td>3.85</td>
<td>35.61</td>
<td>0.32</td>
<td>0.59</td>
<td>0.05</td>
<td>34.41</td>
<td>100.41</td>
</tr>
<tr>
<td>3A1 2.1-2.25</td>
<td></td>
<td>48.48</td>
<td>0.51</td>
<td>10.14</td>
<td>8.59</td>
<td>0.08</td>
<td>11.18</td>
<td>5.60</td>
<td>0.83</td>
<td>1.59</td>
<td>0.07</td>
<td>12.34</td>
<td>99.40</td>
</tr>
<tr>
<td>3B2 2.25-3.0</td>
<td></td>
<td>36.20</td>
<td>0.37</td>
<td>7.30</td>
<td>8.19</td>
<td>0.07</td>
<td>9.96</td>
<td>16.52</td>
<td>0.68</td>
<td>1.12</td>
<td>0.12</td>
<td>18.90</td>
<td>99.42</td>
</tr>
<tr>
<td>3BCk 3.0-4.5</td>
<td></td>
<td>38.89</td>
<td>0.41</td>
<td>7.92</td>
<td>6.45</td>
<td>0.06</td>
<td>10.32</td>
<td>15.57</td>
<td>0.75</td>
<td>1.28</td>
<td>0.10</td>
<td>17.80</td>
<td>99.54</td>
</tr>
<tr>
<td>3Ck 4.5-5.5+</td>
<td></td>
<td>42.78</td>
<td>0.44</td>
<td>8.43</td>
<td>7.03</td>
<td>0.07</td>
<td>9.93</td>
<td>12.97</td>
<td>0.71</td>
<td>1.38</td>
<td>0.08</td>
<td>16.17</td>
<td>99.99</td>
</tr>
</tbody>
</table>

Smectite is the dominant mineral in the paleosol (Table 5.12). Some calcite and most dolomite have been leached from the upper part of the paleosol while the resistant minerals quartz and feldspar are high. Other than this the changes in mineralogy down the paleosol profile are minimal. Serpentine is also quite abundant in the buried soil. In contrast the overlying slope wash is richer in calcite but has less smectite, quartz and serpentinite but is otherwise similar.

Table 5.12 Whole soil mineralogy by X-ray diffraction data for site C13

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (m)</th>
<th>35-50%</th>
<th>15-25%</th>
<th>10%-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2AC 2.0-2.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chronology
A sample of charcoal taken from the ashy material resting on the buried paleosol provided a conventional age of 10,469 ± 193 or a calibrate calendar age of 12,250 ± 700 cal yr BP (Wk9821). This radiocarbon date and extensive loose ashy layer indicates a major fire occurred in this part of the catchment that was quickly followed by burial by over 2 m of layered slope wash sediment. The paleosol beneath the ash is moderately well developed and is formed in colluvial materials. This suggests the lower slopes of the valley side may have been active in the late Pleistocene producing a paler coloured, mottled soil lacking strong horizonation. Perhaps a reflection of the cooler environment and the mottling may reflect winter wetness thought to be a feature of greater seasonality during glacial periods (Wijmstra et al. 1990; Macklin et al. 1995).

Discussion and interpretation
This site clearly illustrates the impact of a major fire on the Leipsokouki landscape at about 12,250 ± 700 BP (Wk9821, calibrated). A moderately deep (1.5m) buried soil (paleosol) with distinct topsoil, leached of most carbonate and with organic matter accumulation, formed on the lower valley slopes. The paleosol, in the lowest part of the slope, has very distinctive coarse orange mottling along root channels, a clear indication of seasonal (winter) wetness. The dull subsoil matrix colours (2.5Y 5/3) also support the notion of seasonal wetness. The buried soil itself appears to have formed in colluvial slope deposits as it contains angular fragments which “float” in the finer matrix. The subsoil 3B2 also contains calcium carbonate fragments (20 – 30 mm dia.), although they do not appear to be nodules in growth position, and are likely to have been transported to the site. Calcium carbonate has been precipitated along tubular pores in the 3BCk and 3Ck (Plate 5.10). However the soil indicates a moderate period of stable soil forming conditions prior to 12 cal kyr BP followed by a major fire on the hill slope. This appears to have been immediately followed by hill slope erosion, probably on the steeper slopes above the site (Figure 5.5), and transport of slope wash alluvium to the site, burying it to with 2-3 m of fine texture sediment.

In the lower parts of the site the paleosol appears to overlie bedded fine textured alluvium. However further upslope the alluvium cuts out and the colluvial profile forms above the Tertiary bedrock.
On the lower slopes at site C13 a wedge shaped pocket of loose ferruginised wood fragments were found inset into the 3A1 horizon (refer to plates 5.11 - 5.12). The material is quite unusual and may be anthropogenic. The other possible explanation is it represents a localised accumulation of ferruginised wood fragments washed into a pre-existing slope hollow. This seems harder to believe, as the depression the material is deposited in is quite angular. However the material is fragmentary and loose indicating it is likely to have been ferruginised at another site and by some means has been transported to the site. If it were slope wash then one might have expected it to also be deposited on the slopes above and below the deposit.

Above the site, on the eroding modern land surface are angular fragments of porous iron oxide formation (5-10 cm dia.) with impressions of stems, grasses and leaf fossils. The leaf fossils were identified as salix (willow, see Plate 5.11 G-I) (Morris and Baker 2004). The material appears to be derived from erosion of the paleosol where it is exposed further up slope. The ferruginised plant material was found in shallow gullies that are now actively cutting into the modern soil surface on slopes above the site (see Plate 5.12). This ferriferous material and the presence of mottles in the paleosol horizons suggest water logging and mobilisation of iron may have been a feature of this landscape in the last glaciation. A factor that is not uncommon due to the lower moisture demands of grasses thus a greater net groundwater recharge during the drier glacial period (Goudie 1995). Macklin et al. (1995) and Wijmstra et al. (1990) have indicated greater seasonality and winter wetness in the glacial periods in northern Greece.

**Site C12 Syndendron alluvium buried by slope deposits at Tsifliki**

Site C12 is located in the upper catchment near Tsifliki at latitude 40.1430° and longitude 21.3569° (see Figure 5.8). Section C12 is 60 m upstream of site C11 and 80 m down slope of soil profile P42 (see Doyle 1990). Doyle (1990) noted four colluvial layers filling a fossil gully at site P42. The pedogenic colluvia at P42 showed leaching of carbonate to a depth of 3 m. The soil colluvia in site C12 are also leached of carbonate. Site C12 has a similar stratigraphy to P42 but dating has shown Doyle’s suggestion the colluvial material was probably late glacial is not quite correct; the lower colluvial units are in fact early Holocene. Site C12 is exposed in a road cutting
on the lower part of a 25 degree slope. A sequence of four colluvial deposits, mostly
derived from soil materials, dominate the upper part of the section. The lower section
exposes Syndendron alluvium that overlies an eroded soil material forming from
colluvium (Plate 5.14). Details of soil colour, structure and texture are provided in
Table 5.13, additional notes and observations on the materials are provided below and
in micrographs in Plate 5.14.

**Field stratigraphy and microscopy**

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.35 m</td>
<td>AB</td>
<td>Modern soil, olive brown, weak porous structure with sub-angular lithic fragments set in silty clay loam matrix indicating the material is of colluvial origin.</td>
</tr>
<tr>
<td>0.4 – 1.2 m</td>
<td>2AB</td>
<td>Brown (7.5YR hue), strongly structured, few &lt;1 mm lithic grains, has strong angular pedality, material appears to be pedogenic colluvium.</td>
</tr>
<tr>
<td>1.2 – 2.0 m</td>
<td>2BC</td>
<td>Brown (10YR hue) sub-angular lithic fragments (1-6 mm) floating in earthy matrix indicating material in soil-colluvium.</td>
</tr>
<tr>
<td>2.0 – 2.25 m</td>
<td>3A1</td>
<td>Very dark greyish brown, well-structured, silty light clay topsoil containing charcoal and dated at 7,500 ± 250 cal yrs BP.</td>
</tr>
<tr>
<td>2.25 – 3.8 m</td>
<td>3B2</td>
<td>Moderately structured subsoil of material above, sub-angular lithic fragments and stratigraphic position suggest material is colluvial.</td>
</tr>
<tr>
<td>3.8 – 4.1 m</td>
<td>4AB</td>
<td>Very dark greyish brown, well-structured, buried topsoil that is radiocarbon dated to 9,900 ± 300 BP (calibrated age Wk 9917).</td>
</tr>
<tr>
<td>4.1 – 5.2 m</td>
<td>4B2</td>
<td>Subsoil with horizon containing sub-angular lithic fragments (1-10 mm dia.) in earthy matrix suggests material is pedogenic colluvium.</td>
</tr>
<tr>
<td>5.2 – 6.7 m</td>
<td>5C</td>
<td>Discontinuous wedge of alluvial sediment that cuts out in left part of section (see Plate 5.14). Stratified fine textured alluvium, or variable depth, thickens to right-hand side of section.</td>
</tr>
</tbody>
</table>
5.2 – 5.3 m  6ABk  Truncated remnant of a soil profile formed in slope colluvium, that underlies the Syndendron alluvium, the dual depths relate the discontinuous and wedge-shaped thickening of the alluvium in the right of the section. Upper part of truncated soil was radiocarbon dated to 10,955 ± 215 BP (Wk9916, calibrated date).

5.3 – 6.5 m+ 6BCk  Dark greyish brown earthy matrix with sub-angular and angular fragments of sandstone floating in matrix suggesting the material is of colluvial origin.

Table 5.13  Field morphology data for section C12

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Depth (m)</th>
<th>Sample description</th>
<th>Field Texture</th>
<th>Moist Colour</th>
<th>React HCl</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB 0-0.35</td>
<td>Recent olive brown surface soil</td>
<td>ZCL</td>
<td>2.5Y</td>
<td>4</td>
<td>3</td>
<td>1.5 PO 2-20mm</td>
</tr>
<tr>
<td>2AB 0.4-1.2</td>
<td>Reddish brown soil colluvium sampled at approximately 1.6 m</td>
<td>ZLC</td>
<td>7.5YR</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>2BC 1.2-2.0</td>
<td>Reddish brown soil colluvium</td>
<td>ZLC</td>
<td>10YR</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>3A1 2.0-2.25</td>
<td>1st buried soil dated 7.5 kyr BP Soil like colluvium sampled at 3.2-3.4</td>
<td>ZLC</td>
<td>2.5Y</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3B2 2.25-3.8</td>
<td>Soil like colluvium sampled at 4.5-4.7m</td>
<td>ZCL</td>
<td>10YR</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>4AB 3.8-4.1</td>
<td>2nd buried soil dated 9.9 Ka Soil like materials sampled at 4.5-4.7m</td>
<td>ZCL</td>
<td>10YR</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>4B2 4.1-5.2</td>
<td>Soil like materials sampled at 4.5-4.7m</td>
<td>ZLC</td>
<td>2.5Y</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>5C 5.2+</td>
<td>Wedge of alluvium – not sampled</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6ABk 5.2-5.3</td>
<td>Basal soil that cuts under alluvium dated to 11 cal kyr BP Calcareous horizon of buried soil sample from 6.0-6.2 m (debris flow)</td>
<td>ZCL</td>
<td>2.5Y</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>6BCk 5.3-6.5+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5.14  Basic chemical properties of site C12

<table>
<thead>
<tr>
<th>Horiz.</th>
<th>Depth (m)</th>
<th>Sample description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 Soil:water</th>
<th>EC μS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB 0-0.35</td>
<td>Recent grey surface soil</td>
<td>-</td>
<td>0.72</td>
<td>7.8</td>
<td>227</td>
</tr>
<tr>
<td>2AB 0.4-1.2</td>
<td>Sampled at 0.7-0.9 Red brown soil sampled at approximately 1.6m</td>
<td>-</td>
<td>0.48</td>
<td>7.4</td>
<td>95</td>
</tr>
<tr>
<td>2BC 1.2-2.0</td>
<td>Reddish brown soil colluvium sampled at approximately 1.6 m</td>
<td>-</td>
<td>0.21</td>
<td>7.6</td>
<td>94</td>
</tr>
<tr>
<td>3A1 2.0-2.25</td>
<td>1st buried soil with charcoal sampled</td>
<td>-</td>
<td>0.44</td>
<td>7.7</td>
<td>103</td>
</tr>
<tr>
<td>3B2 2.25-3.8</td>
<td>Soil like colluvium sampled at 3.2-3.4</td>
<td>-</td>
<td>0.26</td>
<td>8.1</td>
<td>148</td>
</tr>
<tr>
<td>4AB 3.8-4.1</td>
<td>Soil like materials sampled at 4.5-4.7m</td>
<td>-</td>
<td>0.31</td>
<td>7.7</td>
<td>145</td>
</tr>
<tr>
<td>4B2 4.1-5.2</td>
<td>Soil like materials sampled at 4.5-4.7m</td>
<td>-</td>
<td>0.23</td>
<td>7.8</td>
<td>149</td>
</tr>
<tr>
<td>5C 5.2+</td>
<td>Wedge of alluvium – not sampled</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6ABk 5.2-5.3</td>
<td>Basal soil that cuts under alluvium</td>
<td>-</td>
<td>0.15</td>
<td>8.5</td>
<td>121</td>
</tr>
<tr>
<td>6BCk 5.3-6.5+</td>
<td>BC of basal buried soil sample at 6.0-6.2 m (debris flow)</td>
<td>-</td>
<td>0.11</td>
<td>8.6</td>
<td>109</td>
</tr>
</tbody>
</table>

Basic soil chemical properties

The organic carbon is higher in the modern topsoil, but over all the organic carbon values are low in this soil section. The organic carbon is higher in each of the buried topsoils (A1 and AB type horizons) than in the respective subsoils supporting the
stratigraphic separation of soil layers. The soil pH values also tend to be lower in these topsoil layers in comparison with the associated subsoil horizon. The two buried topsoils (3A1 and 4AB) have strong soil structural development (Table 5.13 and Plate 5.15).

**XRF and XRD analysis of samples**

This soil is higher in silica, titanium and potassium oxides than the other soil materials discussed in this chapter (Table 5.15). The higher potassium seems to relate to high mica levels while moderate quartz and mica levels can explain the high silica. The soil materials are low in calcium oxide apart from the calcareous 6ABk and 6BCk (strong reaction to dilute HCl) at the base of the section. Magnesium oxide is also low in the 6ABk in comparison with the other soil materials in this section and may relate to lower smectite levels.

<p>| Table 5.15 Major elemental analysis by X-ray fluorescence (%) for site C12 |
|--------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|</p>
<table>
<thead>
<tr>
<th>Horiz</th>
<th>Depth (m)</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>0-0.35</td>
<td>61.32</td>
<td>0.67</td>
<td>13.49</td>
<td>6.78</td>
<td>0.10</td>
<td>4.40</td>
<td>1.93</td>
<td>1.81</td>
<td>2.73</td>
<td>0.07</td>
<td>6.37</td>
<td>99.67</td>
</tr>
<tr>
<td>2AB</td>
<td>0.4-1.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2BC</td>
<td>1.2-2.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3A1</td>
<td>2.0-2.25</td>
<td>60.48</td>
<td>0.64</td>
<td>13.87</td>
<td>7.72</td>
<td>0.11</td>
<td>5.27</td>
<td>1.13</td>
<td>1.73</td>
<td>2.74</td>
<td>0.09</td>
<td>5.26</td>
<td>100.09</td>
</tr>
<tr>
<td>3B2</td>
<td>2.25-3.8</td>
<td>61.25</td>
<td>0.66</td>
<td>14.00</td>
<td>7.13</td>
<td>0.11</td>
<td>4.93</td>
<td>1.19</td>
<td>1.82</td>
<td>2.94</td>
<td>0.10</td>
<td>5.41</td>
<td>99.54</td>
</tr>
<tr>
<td>4AB</td>
<td>3.8-4.1</td>
<td>57.56</td>
<td>0.67</td>
<td>14.75</td>
<td>8.39</td>
<td>0.11</td>
<td>6.16</td>
<td>1.13</td>
<td>1.55</td>
<td>2.90</td>
<td>0.10</td>
<td>6.39</td>
<td>99.72</td>
</tr>
<tr>
<td>4B2</td>
<td>4.1-5.2</td>
<td>58.96</td>
<td>0.63</td>
<td>13.61</td>
<td>7.78</td>
<td>0.11</td>
<td>7.48</td>
<td>1.18</td>
<td>1.61</td>
<td>2.71</td>
<td>0.10</td>
<td>6.11</td>
<td>100.28</td>
</tr>
<tr>
<td>5C</td>
<td>5.2+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6ABk</td>
<td>5.2-5.3</td>
<td>41.64</td>
<td>0.44</td>
<td>9.80</td>
<td>8.50</td>
<td>0.08</td>
<td>6.34</td>
<td>15.57</td>
<td>1.30</td>
<td>2.02</td>
<td>0.12</td>
<td>16.66</td>
<td>99.37</td>
</tr>
</tbody>
</table>

Smectite is the dominant mineral at the site followed by quartz and mica. Plagioclase and chlorite are also higher in this part of the catchment. Calcite is high in the lower part of the section but otherwise is at the lowest levels seen in the catchment. The mineralogical difference in the bulk soil materials at this site is probably a reflection of the greater amount of fine sandstones that are more mica rich than the mudstone layers that dominate the mid catchment. The sandstone has been shown to supply more mica and quantity and less smectite (Doyle 1990). It may be that the pedogenic colluvia in the section are derived from mature soils on sandstone, such as C7 and C10, rather than the smectite rich and calcareous cover beds at sites CDS1 – CDS4 (see Chapter 4).
Plate 5.14 Site C12 at Tsifliki (Plates A and B). The upper photo (A) show the entire section and all three radiocarbon dates. Four layers of colluvium cap the alluvium seen in the lower part of the section. The lower photograph (B) shows the 2nd buried colluvial soil at top of yellow tape (2m). At the base of the tape is the sloping soil developed beneath the fine textured, layered Syndendron alluvium.
Figure 5.8 Location map of sites C12, C11 and C1 and soil description P42 of Doyle 1990.
Figure 5.9 Radiocarbon calibration curves for site C12 after Stuiver et al. (1998) and software from Bronk Ramsey (2002).
0 – 0.4 m  AB
Modern soil with sub-angular lithic fragments (1-5 mm, B), weak pedality, open porous fabric (B).

0.4 – 1.2 m  2B2
Buried layer formed of reddish brown soil-like colluvium with strong angular pedality (A), some smooth ped surfaces (B),

1.2 – 2.0 m  2BC
Moderate angular pedality, soil contains sub-angular lithic fragments (1-6 mm, B), porous ped surfaces (B).

2.0 – 2.25 m  3A1
1st buried topsoil horizon, with fragments of charcoal, strong pedality, smooth ped surfaces soil dated to 7,500 ± 250 cal yrs BP (Wk9918)

Plate 5.15 Micrographs of soil materials from site C12 (scale 1 mm graduations)
2.25 – 3.8 m 3B2
Soil colluvium, aggregates contain lithic fragments and calcium carbonate particles, porous ped surfaces

3.8 – 4.1 m 4AB
2nd buried topsoil, with strong pedality and smooth ped surfaces, fragments of both carbonate and charcoal in layer

4.1 – 5.2 m 4B2
Subsoil of 2nd buried soil, moderate pedality, sub-angular lithic fragments (1-6 mm) present

5.2 – 5.3 m 6ABk
Truncated soil profile, weak structure (A) highly calcareous with calcium carbonate lining pores, lithic fragments (B)

5.3 – 6.5+ m 6BCk
C horizon of truncated soil above, weak structure (A) note soft calcium carbonate lining pores (B)

Plate 5.15 Continued site C12 soil materials, scale 1 mm graduations
Table 5.16  Whole soil mineralogy by X-ray diffraction analysis for site C12

<table>
<thead>
<tr>
<th>Horiz</th>
<th>Depth (m)</th>
<th>25%-35%</th>
<th>15%-25%</th>
<th>10%-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>0-0.35m</td>
<td>Smectite</td>
<td>Quartz, Mica</td>
<td>Plag., Chl.</td>
<td>K-Feldspar</td>
<td>Serpentine</td>
<td>Cal, Dolo, Talc</td>
</tr>
<tr>
<td>2BC</td>
<td>1.2-2.0m</td>
<td>Smectite</td>
<td>Quartz, Mica</td>
<td>Plag., Chl.</td>
<td>Chlorite</td>
<td>K-Feld, Serp</td>
<td>Epidote, Talc</td>
</tr>
<tr>
<td>3A1</td>
<td>2.0-2.25m</td>
<td>Smectite</td>
<td>Quartz, Mica</td>
<td>Plag., Chl.</td>
<td>Chl, Serp</td>
<td>Serpentine, K-Feldspar</td>
<td>Talc, Calcite</td>
</tr>
<tr>
<td>3B2</td>
<td>2.25-3.8m</td>
<td>Smectite</td>
<td>Quartz, Plag., Chl.</td>
<td>Serpentine, K-Feldspar, Calcite, Talc, Sepiolite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4AB</td>
<td>3.8-4.1m</td>
<td>Smectite</td>
<td>Mica, Quartz</td>
<td>Plag., Chl.</td>
<td>Plagioclase</td>
<td>Serp, K-Feld</td>
<td>?Epidote, Talc</td>
</tr>
<tr>
<td>4B2</td>
<td>4.1-5.2m</td>
<td>Smectite</td>
<td>Mica, Quartz</td>
<td>Chl., Plag.</td>
<td>Serpentine</td>
<td>K-Feldspar</td>
<td>Calcite, Talc</td>
</tr>
<tr>
<td>6ABk</td>
<td>5.2-5.3m</td>
<td>Smec., Cal., Mica</td>
<td>Qtz., Chl.</td>
<td>Serpentine, Plagioclase</td>
<td>K-Feldspar, Dolomite</td>
<td>Talc, Sepiolite</td>
<td></td>
</tr>
</tbody>
</table>

Chronology
Near the base of the section an eroded colluvial soil profile has provided an AMS radiocarbon date of 10,955 ± 300 cal yr BP (see Figure 5.9, Wk9916). The truncated soil material is covered with fine textured alluvium, presumably the Syndendron alluvium. This alluvium is capped by a colluvial soil dated to 9,900 ± 400 BP (calibrated, Wk9917) and indicates the Syndendron alluvial event was completed by the beginning of the Holocene. Colluvial soil materials continued to be transported to the site between 10 – 7.5 cal kyr BP. Charcoal associated in the topsoil layers of each colluvial unit suggest burning of the slopes is related to the soil creep process supplying the colluvium. The upper 2 m of the section indicates colluvial activity continued after 7,500 cal yrs BP, with a further two undated colluvial deposits.

Discussion and interpretation
A truncated soil (paleosol) is buried by alluvium after 11 ka BP. This suggests the alluvial material is the later part of the Syndendron alluvium. The lower part of the section indicates the stream was incised prior to 11 kyr BP and soils developed on hill slope colluvium. This was followed by active erosion on the slopes and deposition of alluvium in the valley from prior to 11 kyr BP till before 10 kyr BP. After 10 kyr BP a sequence of soil-derived colluvial layers cap the Syndendron alluvium. This indicates the movement of pedogenic colluvium from the surrounding hill slopes to the valley floor during the early Holocene. Similar transport of pedogenic colluvia occurred in sites C17, C9 and P59. The soil erosion observed at the site has occurred long before Humans have traditionally been associated with erosion i.e., Bronze age and Greco-Roman periods yet this site shows active soil creep from 10 kry BP till well after 7.5 kry BP. Perhaps it relates to the wetter climates of the early Holocene.
The uppermost colluvial deposit is very pale in colour (2.5Y 4/3) and lacks strong soil structure indicating it is derived from a more eroded landscape i.e., derived from BC and C horizons. However, lack of charcoal prevented dating of this unit. Sometime after the last dated soil the area adjacent to the section has been re-incised to its present level.

The depositional sequence is as follows: IN-CO-SO-SW/OB-CO-SO-CO-SO-CO-
CO-IN.

**Site C11 Tsifliki landslide**

The site is located a few metres above the bedrock base of the modern streambed at latitude 40.1417° and longitude 21.3563° (see Figure 5.8). The section is 300 m NW of Tsifliki and 100 m down stream of site C12. The slope angles above the site are 25° - 30° and appear to have been a source of colluvial and debris flow sediment to the site (see Plates 5.16 and 5.17).

The section is described in two parts (see Unit A and Unit B outlined below) due to lateral changes along the section. On the left-hand side of the section colluvial materials cap a debris flow deposit (Unit A), while on the right-hand side of the section soil-colluvium caps two alluvial units (Unit B). Field notes on the stratigraphic materials are provided below and details of some of the soil colour, structure and texture are provided in Table 5.17 with additional information provided on the micrographs in Plate 5.17.

**Field stratigraphy**

**Unit A or left hand side of section (colluvium over debris flow)**

- **0 – 0.7 m A1** Modern topsoil, dark greyish brown colour, strong reaction to HCl, common angular stones (up to 60 mm dia.) set in fine earthy matrix, material appears to be colluvium.
- **0.7 – 1.2 m 2AB** Moderately structured, darker brown soil colluvium with common angular stones and gravels in earthy matrix.
- **1.2 – 2.6 m 3B2** Debris flow with large pieces (0.5x1.5m dimension) of intact dark brown (7.5YR 3/4, not sampled) soil incorporated in the olive
brown debris flow matrix with angular lithic fragments up to 20 mm dia.

2.6 – 3m+ 3C Olive grey, hard, compact, with common sub-angular stones and gravels, massive debris flow deposit dated at $7,490 \pm 180$ cal yr BP (Wk 9819).

Unit B right-hand side of section (colluvium over alluvial units)

0 – 0.4 m A1 Modern topsoil from recent colluvium, dark greyish brown colour, strong reaction to HCl, common angular stones set in fine earthy matrix

0.4 – 1.3 m 2AB Dark greyish brown soil-like colluvium with charcoal rich layer sampled at 1.0 m. The charcoal provided a date of $5,050 \pm 450$ cal yr BP (Wk 9820).

1.3 – 1.6 m 3C Very pale brown, fine textured bedded alluvium.

1.6 – 1.8 m 4AB Faint, darker brown layer, resembles incipient buried soil material on alluvial/colluvial unit.

1.8 – 2.1 m 4C Light brown, fine textured alluvium, over bank type alluvium, compact.

2.1 – 3.7 m 4C Gravelly, alluvial channel deposit with charcoal extracted from the upper part of this unit dated at $11,800 \pm 550$ cal yr BP (Wk9915).

It is likely the upper alluvial deposit in Unit B (1.8 – 2.1 m) is derived from the debris flow in Unit A (1.2 – 2.6m). This can be seen in the Plates 5.16 – 5.17 which show the upper part of the debris flow merging into the upper alluvium.

The field texture data reveal the soil and colluvial materials are fine sandy or silty clay loams and light clays. All the soil and colluvial materials include angular and sub-angular coarse fragments that float in the earthy matrix (see Plates 5.16 - 5.17). The soil-like materials (A1, AB and B2 type horizons) also have moderate soil structure and dull Munsell colours. The reddest hues occur in the large encased pieces of soil profile entrained in the upper part of the debris flow (see Plate 5.16).
Table 5.17  Morphological details of some of the key materials in section C12

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Unit A</th>
<th>Hor</th>
<th>Sample Type</th>
<th>Field Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>React HCl</th>
<th>Soil Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.7</td>
<td>A1</td>
<td>Modern recent topsoil, sampled at 0.1-0.3 m</td>
<td>FSCL</td>
<td>2.5Y 4 2</td>
<td>2.5Y 5 2</td>
<td>3</td>
<td>2 PO</td>
<td>0-20mm</td>
</tr>
<tr>
<td>0.7-1.2</td>
<td>2AB</td>
<td>2nd colluvium sampled at 0.8-0.9m</td>
<td>ZC</td>
<td>2.5Y 4 2</td>
<td>2.5Y 6 2.5</td>
<td>3</td>
<td>2 PO</td>
<td>2-10mm</td>
</tr>
<tr>
<td>1.2-2.5</td>
<td>3B2</td>
<td>Main part of debris flow at 2.0-2.1m</td>
<td>ZLC-FSCL</td>
<td>2.5Y 4 2</td>
<td>2.5Y 6 3</td>
<td>1</td>
<td>2 PO</td>
<td>5-20mm</td>
</tr>
<tr>
<td>2.6-3.0</td>
<td>3C</td>
<td>Hard, massive base of debris flow dated at 7,490 + 180 BP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The soil chemical data indicate the modern topsoil has the highest organic carbon levels (Table 5.18). The other soil-colluvial layers and faint buried soils have the intermediate levels of carbon. The lowest organic carbon occurs in the upper part of the debris flow (3B2). Soil pH is highest in the calcareous debris flow material and lowest in the identified topsoil-like materials (AB and A1 type horizon designations).

Table 5.18  Basic chemical properties of site C11

<table>
<thead>
<tr>
<th>Hor Unit A</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0-0.7</td>
<td>Modern recent topsoil, sampled at 0.1-0.3 m</td>
<td>1.32</td>
<td>7.8</td>
<td>420</td>
</tr>
<tr>
<td>2AB</td>
<td>0.7-1.2</td>
<td>2nd colluvium sampled at 0.8-0.9m</td>
<td>0.67</td>
<td>7.8</td>
<td>217</td>
</tr>
<tr>
<td>3B2</td>
<td>1.2-2.5</td>
<td>Main part of debris flow – encased red-brown soil at 2.0-2.1m</td>
<td>0.38</td>
<td>8.2</td>
<td>166</td>
</tr>
<tr>
<td>3C</td>
<td>2.6-3.0</td>
<td>Hard, massive base of debris flow dated at 7,490 + 180 BP</td>
<td>0.54</td>
<td>8.4</td>
<td>151</td>
</tr>
</tbody>
</table>

XRF and XRD analysis of samples

The limited X-ray fluorescence data presented in Table 5.19 indicate the highest oxide calcium oxide levels occur in the lower horizons and materials. This is also where the greatest levels of “loss” occurred and probably represent the carbon and water loss associated with the calcium carbonate. The calcium oxide and “loss” values are the reverse of the silica values and show the impact the calcium carbonate levels have on
Plate 5.16 Site C11 near Tsifliki showing pale debris flow material with reddish soil material encased within, this is dated at 7,490 ± 180 years BP (WK9819) and is capped by soil colluvium dated to 5,050 ± 450 years BP (WK9820). Charcoal extracted from alluvium (assistant collecting) in background was dated at 11,800 ± 500 years BP (WK9915). This is capped by younger alluvium which appears to be re-worked components of the debris flow to the left of frame. Closer image shown below.
Plate 5.17 Site C11 Tsifliki, showing a close-up view of the buried colluvial unit capping alluvial materials. The field assistant (dressed for dinner) is pointing at charcoal sample site now dated at 5,050 ± 450 years BP (WK9820 calibrated) while she stands on the Syndendron alluvium dated here at 11,800 ± 550 BP (calibrated Wk9915). The debris flow deposit has come down from the slopes above and partly buried the alluvium, suggesting incision of the alluvium had occurred prior to about 7,490 ± 180 years BP (WK9819), perhaps a potential trigger mechanism. Slumping off the side of the debris flow and also alluvial reworking can be seen in the mid section (ca. 1.3-2.2 m)
Figure 5.10  Radiocarbon calibration curves for site C11 after Stuiver et al. (1998) and software from Bronk Ramsey (2002).
Unit A  0 - 0.7 m  
**A1**
Moderate pedality (A, C), common sub-angular lithic fragments of 2-10 mm (arrows in B), slightly calcareous.

Unit A  0.7 - 1.2 m  
**2AB**
Moderate pedality, common sub-angular lithic fragments (2-10 mm), calcareous.

Unit A  1.2 - 2.6 m  
**3B2**
Moderate pedality, common sub-angular lithic fragments (2-20 mm).

Unit A  2.6 - 3.0 m  
**3C**
No soil structure, highly calcareous, common sub-angular lithic fragments (2-200 mm)

Unit B at 1m  
**AB**
Moderate pedality (A) with some smooth surfaces and worm channels (C), sub-angular lithic fragments (B)

Unit B  1.5 – 2.0 m  
**2AB**
Moderate pedality (A) with some smooth surfaces and worm channels (C), sub-angular lithic fragments (B)

Plate 5.18 Micrographs of site C11 (scale in mm).
the X-ray fluorescence data. Potassium oxide levels are also high and are a reflection of the moderate amounts of mica in these soil materials.

Table 5.19  Major elemental analysis by X-ray fluorescence (%) for site C11

<table>
<thead>
<tr>
<th>Unit B</th>
<th>Depth (m)</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>Loss</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0-0.7</td>
<td>48.48</td>
<td>0.51</td>
<td>11.10</td>
<td>6.34</td>
<td>0.10</td>
<td>7.37</td>
<td>8.80</td>
<td>1.41</td>
<td>2.30</td>
<td>0.13</td>
<td>13.43</td>
<td>99.97</td>
</tr>
<tr>
<td>2AB</td>
<td>0.7-1.2</td>
<td>52.26</td>
<td>0.54</td>
<td>11.85</td>
<td>6.74</td>
<td>0.10</td>
<td>6.83</td>
<td>7.10</td>
<td>1.50</td>
<td>2.36</td>
<td>0.11</td>
<td>10.58</td>
<td>99.97</td>
</tr>
<tr>
<td>3B2</td>
<td>1.2-2.5</td>
<td>52.94</td>
<td>0.55</td>
<td>12.34</td>
<td>7.87</td>
<td>0.10</td>
<td>7.34</td>
<td>8.80</td>
<td>1.41</td>
<td>2.34</td>
<td>0.12</td>
<td>10.55</td>
<td>99.97</td>
</tr>
<tr>
<td>3C</td>
<td>2.6-3.0</td>
<td>41.86</td>
<td>0.41</td>
<td>8.26</td>
<td>4.06</td>
<td>0.04</td>
<td>3.82</td>
<td>19.29</td>
<td>1.34</td>
<td>1.61</td>
<td>0.11</td>
<td>18.76</td>
<td>99.55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit B</th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2AB</td>
<td>at 1.0</td>
<td>59.26</td>
<td>0.63</td>
<td>13.48</td>
<td>7.55</td>
<td>0.12</td>
<td>6.29</td>
<td>1.81</td>
<td>1.66</td>
<td>2.59</td>
<td>0.08</td>
<td>6.63</td>
<td>100.11</td>
</tr>
<tr>
<td>4AB</td>
<td>1.6-1.8</td>
<td>47.84</td>
<td>0.49</td>
<td>10.25</td>
<td>5.17</td>
<td>0.08</td>
<td>4.43</td>
<td>13.40</td>
<td>1.56</td>
<td>1.95</td>
<td>0.12</td>
<td>14.91</td>
<td>100.20</td>
</tr>
</tbody>
</table>

The XRD analyses show the materials are dominated by the mineral smectite with quartz and mica as important secondary minerals (Table 5.20). High plagioclase occurs in the upper alluvial unit (Unit B 2AB) and matches well with its suspected origin, the adjacent debris flow deposit (Unit A 3B2 and 3C), which is also high in plagioclase. Calcite appears to have been partly leached from the upper part of the Unit A 3B2 and accumulated in the 3C. The younger overlying colluvium materials (A1 and 2AB in Unit A) have higher calcite levels than the 3B2 indicating they have had less time for leaching. The lowest calcite levels occur in the Unit B 2AB which is a colluvial soil-like material dated 5,050 ± 450 BP (calibrated Wk9820). The highest levels of calcite occur in the substrate materials (Unit A 3C and Unit B 2AB).

Table 5.20  Whole soil mineralogy by X-ray diffraction analysis for site C12

<table>
<thead>
<tr>
<th>Unit A</th>
<th>Depth</th>
<th>25%-35%</th>
<th>15%-25%</th>
<th>10%-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0-0.7</td>
<td>Smectite</td>
<td>Mica, Quartz</td>
<td>Plag, Chl.</td>
<td>Serpentine, Cal</td>
<td>K-Feld, Dolo, Epid.</td>
<td>Talc</td>
</tr>
<tr>
<td>2AB</td>
<td>0.7-1.2</td>
<td>Smec, Mica</td>
<td>Quartz, Chlo.</td>
<td>Plag., Serp., Cal</td>
<td>K-Feldspar</td>
<td>Dolo, Talc</td>
<td></td>
</tr>
<tr>
<td>3B2</td>
<td>1.2-2.5</td>
<td>Smectite</td>
<td>Quartz</td>
<td>Mica, Plag, Chl.</td>
<td>K-Feldspar</td>
<td>Serpentine, Calcite</td>
<td>Dolo, Talc</td>
</tr>
<tr>
<td>3C</td>
<td>2.6-3.0</td>
<td>Smecite</td>
<td>Quartz, Smec, Plag.</td>
<td>Mica</td>
<td>Chl, Serpentine</td>
<td>K-Feldspar, Dolo</td>
<td>Talc</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit B</th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2AB</td>
<td>At 1.0</td>
<td>Smec (35-50%)</td>
<td>Quartz</td>
<td>Mica, Plag, Chl.</td>
<td>Chlorite, Serp</td>
<td>K-Feldspar</td>
<td>Calcite, Talc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4AB</td>
<td>1.5-2.0</td>
<td>Smec., Plag</td>
<td>Cal., Qtz, Mica</td>
<td>Chl, Serp</td>
<td>K-Feldspar</td>
<td>Dol., Talc, Sepiol, Epid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chronology
Charcoal sampled from the lower alluvial unit at the base of the section gave an age of 11,800 ± 550 cal yr BP (WK9915, see Figure 5.10). This date is consistent with the material being part of the Syndendron alluvium. An undated pale brown alluvial unit caps this Syndendron alluvium and is overlain by a soil-like colluvium and dated to
5,050 ± 450 cal years BP (Wk 9820, see Figure 5.10). On the right-hand part of the section a debris flow deposit has been dated to 7,490 ± 180 cal years BP (Wk 9819). This debris flow deposit appears to be the source material for the pale brown upper alluvial unit as indicated in Plates 5.16 and 5.17. The debris flow material grades laterally into this alluvium suggesting the pale brown alluvium is younger than 7.5 kyr but older then 5.0 kyr BP.

**Discussion and interpretation**

At the base of the section is the Syndendron alluvium dated at 11.8 cal kyr BP. This deposit is only a metre above the current stream base, which is on bedrock. The Syndendron alluvium has then been buried by a debris flow deposit at 7.5 cal kyr BP, which has entrained large pieces of soil in its upper part (see Plate 5.16). The main matrix material of the debris flow deposit is olive grey in colour, compact and massive in structure. This suggests it is probably derived from subsoil and bedrock sources, i.e. it is a deep seated erosional product. The upper part of this debris flow deposit contains intact blocks of reddish brown soil, indicating the deposit represents a major erosional event. Whether the upper and lower parts of the debris flow are separated in time is not known. However other examples of debris flows in the catchment have shown they are separated with the younger upper part less than 6.5 cal kyr BP – see site the near by C1 (chapter 7). Such a situation would be consistent with the dating in this site as the upper part of the debris flow is not buried until after about 5 cal kyr BP. This upper part of the debris flow appears to have been reworked to produce a pale yellow fine textured alluvium (Unit B 4AB, not dated). A soil-like colluvium caps this undated pale yellow alluvium at about 5 cal kyr BP.

The C11 section demonstrates that debris flow deposits and land sliding in the catchment results in at least localised alluvial aggradation. It also indicates that when the supply of sediment is reduced the stream is able to re-incise to its bedrock base. Stream re-incision at the site can be shown to have occurred on at least four occasions. Firstly prior to deposition of the Syndendron alluvium i.e., before 11.8 kyr BP. Secondly prior to the deposition of the debris flow, i.e., prior to 7.5 kyr BP. A third time prior to the soil-colluvial deposition at 5 kyr BP but this is only to the level of about 2 m above its present bedrock base and finally in its present form. This site indicates that during the majority of the Holocene the Leipsokouki stream, in this
narrow and steep part of the catchment, has been able to move sediment on the valley floor out to lower, more open parts of the valley with only short periods of sediment storage close to the active channel.

**Site C9 Syndendron alluvium and colluvial soils**

The site is located on an alluvial fan below Paleokastro at longitude 21.3645° and latitude 40.1314° (see Figure 5.3). Recent stream bank erosion has exposed the underlying stratigraphy and provided an opportunity for dating colluvial soils forming above the Syndendron alluvium. Beneath the Syndendron alluvium a distinct dark, silty clay paleosol is exposed. This paleosol slopes (between 30°-10°) down to the valley floor and contains charcoal for AMS dating.

Described below is the field stratigraphy of site C9 and Tables 5.21 and 5.22 providing more data on the sediment properties.

**Field stratigraphy and microscopy**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.3</td>
<td>A1</td>
<td>Modern topsoil, moderate sub-angular pedality, common angular grit and gravel fragments (2-20 mm) indicating the colluvial nature of material.</td>
</tr>
<tr>
<td>0.3 – 0.5</td>
<td>2A1</td>
<td>Strong prismatic to polyhedral structure with few angular gravels floating in the earth matrix indicating the soil material is colluvial in origin.</td>
</tr>
<tr>
<td>0.5 – 0.8</td>
<td>2Ck1</td>
<td>Calcareous subsoil with few angular gravels floating in earthy matrix indicating a colluvial origin for the material. Calcium carbonate encases the peds suggesting it is post depositional (Plate 5.21).</td>
</tr>
<tr>
<td>0.8 – 1.1</td>
<td>2Ck2</td>
<td>Calcareous, white, structure-less, few sub-angular and angular lithic fragments (2-30 mm) indicating material is colluvial, carbonate veins are coating lithic fragments indicating it is post depositional.</td>
</tr>
<tr>
<td>1.1 – 1.5</td>
<td>3AB</td>
<td>Brown soil-like colluvium with distinct angular blocky structure and shiny ped fabric, silty clay texture, very firm dry, some veins of calcium carbonate.</td>
</tr>
</tbody>
</table>
1.5 – 2.0  4A1  Buried dark clay soil with strong polyhedral structure, few 1-
3 mm hard nodules of calcium carbonate, charcoal in soil
dated at 8,085 ± 230 cal yr BP (Wk9914).

2.0 – 2.3 m  4Ck1  Calcareous with carbonate precipitated in veins, common
sub-angular lithic fragments, material forms colluvium
derived subsoil of buried soil above.

2.3 – 3.8 m  4Ck2  Silty to fine sandy alluvium with a fine clast supported,
water-worn gravelly layer at 3.4 m, stratified alluvial
sediment.

3.8 – 3.9  5A1  Thin alluvial soil with charcoal which was sampled but not
sent for radiocarbon dating.

3.9 – 5m  6C1  Stratified fine textured alluvium typical of over-bank type
deposits.

5 – 6.2 m  6C2  Gravelly and in places distinct stone stringers both of water-
worn, rounded and clast-supported alluvium, channel type
deposits.

6.2 – 6.7 m  6C3  Fine textured (sils and sands), bedded alluvium typical of
over-bank type deposits.

6.7 – 6.8 m  7A1  Buried sloping soil (paleosol) with moderate structure and
common lithic fragments of sub-rounded to angular shape
indicating the colluvial nature of the material. The soil
contains charcoal that is dated to 6,140 ± 140 cal yr BP
(WK9912). The soil overlies inter-bedded fine (silty and
sandy) and gravelly alluvium.

All the soil and colluvial materials have a silty clay loam or silty light clay texture.
The buried soil at 1.5 – 3.6 m has a distinctly darker coloured topsoil and slightly
heavier texture than all other horizons in the section (Table 5.12 and Plates 5.19 –
5.20). The soil matrix of the 4A1 (1.5 – 2 m) has no reaction to dilute HCl acid,
however very distinct and hardened calcium carbonate precipitation is obvious on
some pore linings (see Plate 5.21). The buried pedogenic colluvium at 1.1 – 1.5 m
(3AB) has a very distinct angular block structure and shiny ped surfaces (Plates 5.19
and 5.21). All the buried soils and pedogenic colluvia show higher soil structural
development and have lower reaction to HCl in their upper profile, presumably due to leaching of carbonate.

Table 5.21  Morphological details of some of the key materials in section C9

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Hor</th>
<th>Description</th>
<th>Text</th>
<th>Moist Colour</th>
<th>Structure Dev</th>
<th>Ty</th>
<th>Size</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.2</td>
<td>A1</td>
<td>Modern topsoil</td>
<td>ZCL+</td>
<td>2.5Y</td>
<td>2</td>
<td>PO</td>
<td>2-5mm</td>
<td>2</td>
</tr>
<tr>
<td>0.2-0.5</td>
<td>2A1</td>
<td>1st buried topsoil</td>
<td>ZLC</td>
<td>2.5Y</td>
<td>3</td>
<td>PO</td>
<td>2-10mm</td>
<td>1</td>
</tr>
<tr>
<td>0.5-0.8</td>
<td>2Ck1</td>
<td>1st buried soil calcic horizon</td>
<td>ZCL</td>
<td>2.5Y</td>
<td>5</td>
<td>SB</td>
<td>5-20mm</td>
<td>3</td>
</tr>
<tr>
<td>0.8-1.1</td>
<td>2Ck2</td>
<td>White calcareous colluvial mat.</td>
<td>ZCL</td>
<td>5Y</td>
<td>6</td>
<td>SG</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>1.1-1.5</td>
<td>3AB</td>
<td>2nd buried soil mat. – red brown</td>
<td>ZLC-</td>
<td>2.5Y</td>
<td>4</td>
<td>AB</td>
<td>10-20mm</td>
<td>1</td>
</tr>
<tr>
<td>1.5-2.0</td>
<td>4A1</td>
<td>3rd buried soil – v. dk brown. dated to 8,085 ± 230 BP</td>
<td>ZLC+</td>
<td>10YR</td>
<td>2</td>
<td>PO</td>
<td>20-50mm</td>
<td>0</td>
</tr>
<tr>
<td>2.0-2.3</td>
<td>4Ck</td>
<td>3rd buried soil calcic horizon</td>
<td>ZLC-</td>
<td>2.5Y</td>
<td>5</td>
<td>PO</td>
<td>2-10mm</td>
<td>4</td>
</tr>
<tr>
<td>2.3-3.6</td>
<td>4C</td>
<td>Alluvium sampled at 3.25 m</td>
<td>ZCL-</td>
<td>2.5Y</td>
<td>6</td>
<td>SG</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>at 3.8</td>
<td>5A1</td>
<td>Buried alluvial soil with charcoal</td>
<td>ZLC-</td>
<td>2.5Y</td>
<td>4</td>
<td>PO</td>
<td>10-50mm</td>
<td>2</td>
</tr>
<tr>
<td>5.5-7</td>
<td>7A1</td>
<td>Basal sloping soil with charcoal dated to 6,140 ± 150 BP</td>
<td>ZLC</td>
<td>2.5Y</td>
<td>3</td>
<td>PO</td>
<td>20-50mm</td>
<td>2</td>
</tr>
</tbody>
</table>

Basic soil chemical properties

The highest organic carbon level occurs in the modern topsoil. The second and third buried soils show a progressive decline in organic carbon with depth. The soil pH trends in these two profiles have opposite trends to carbon and probably reflect the impact of soil organic matter on soil pH and also the impact of leaching of calcium carbonate. The slightly higher pH in the modern topsoil (A1) maybe due to active incorporation of calcareous materials associated with recent deposition from erosion and also cultivation associated with cereal growing. Electrical conductivity is low throughout most of the profile but peaks at 350 μS/cm [slightly saline, (Doyle 1993)] in this upper layer, perhaps a reflection of added fertilisers, dissolution of carbonate and some concentration of salts due to evaporation of capillary moisture at the soil surface.
Plate 5.19  Site C9, photograph A showing entire section with the sloping basal soil visible and overlain by alluvium and the alluvial and colluvial soil materials. Photograph B below shows a close-up view of upper part of the section and location of upper radiocarbon date.

Modern soil underlain by calcareous colluvium (A1 – 2Ck2)

Reddish brown soil colluvium (1.1 –1.5 m, 3AB)

Buried soil (4A1 – 4Ck2) radiocarbon dated at 1.5 – 2.0 m to 8,085 ± 230 BP (calibrated WK9914)
Plate 5.20 Site C9 or P1 Paleokastro forms the hill in background. Photo above shows soil section in gully side below Paleokastro. Lower photo shows soils and alluvium in section. Sloping basal soil can be seen descending under alluvium.
Figure 5.11 Radiocarbon calibration curves for site C9 after Stuiver et al (1998) and software from Bronk Ramsey (2002). Note C9a is younger than C9b despite its lower stratigraphic position suggesting an error with one or other dates. As the soil dated as Wk9912 appears to underlie the Syndendron alluvium it is more likely to be erroneous. In addition a younger date could more easily be derived by contamination of younger carbon from humus or rootlets.
Plate 5.21 Microscopy for site C9 (scale 1mm)
1.5 – 2.0 m 4A1
Strong angular pedality, waxy surfaces, 1-3 mm hard nodules of carbonate (C), fragments of charcoal dated to 8,085 ±230 BP (calibrated Wk 9914)

2.0 – 2.3 m 4Ck1
1-20 mm subang. lithics fragments (A), carbonate in root channels and cracks (B, C), entrained ped in matrix (C)

2.3 – 3.8 m 4Ck2
Calcareous alluvium, rounded lithics (B), carbonate in pores and cracks (A, C)

3.8 - 3.9 m 5A1
Moderate angular pedality, fragments of charcoal (A), sub-rounded lithics (B, alluvial), carbonate in pores and cracks

6.7 - 6.8 m 7A1
Moderate angular pedality, fragments of charcoal, sub-rounded to angular lithics (A, B = colluvial.), carbonate in pores and cracks, charcoal dated to 6,140 ± 150 (Wk 9912).

Plate 5.22 continued  Microscopy for site C9 (scale 1mm)
Table 5.22  Basic chemical properties of site C9

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC 1:5 μS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0-0.2</td>
<td>Modern topsoil</td>
<td>3.46</td>
<td>7.9</td>
<td>350</td>
</tr>
<tr>
<td>2A1</td>
<td>0.2-0.5</td>
<td>1st buried topsoil</td>
<td>0.97</td>
<td>7.8</td>
<td>172</td>
</tr>
<tr>
<td>2Ck1</td>
<td>0.5-0.8</td>
<td>1st buried soil calcic horizon</td>
<td>0.86</td>
<td>8.2</td>
<td>126</td>
</tr>
<tr>
<td>2Ck2</td>
<td>0.8-1.1</td>
<td>White calcareous colluvial mat.</td>
<td>0.74</td>
<td>8.4</td>
<td>138</td>
</tr>
<tr>
<td>3AB</td>
<td>1.1-1.5</td>
<td>2nd buried soil mat. – red brown</td>
<td>1.63</td>
<td>8.1</td>
<td>150</td>
</tr>
<tr>
<td>4A1</td>
<td>1.5-2.0</td>
<td>3rd buried soil – v. dk brown. dated to 8,085 ± 230 BP</td>
<td>1.60</td>
<td>8.1</td>
<td>126</td>
</tr>
<tr>
<td>4Ck</td>
<td>2.0-2.3</td>
<td>3rd buried soil calcic horizon</td>
<td>0.89</td>
<td>8.3</td>
<td>131</td>
</tr>
<tr>
<td>4C</td>
<td>2.3-3.6</td>
<td>Alluvium sampled at 3.25 m</td>
<td>0.76</td>
<td>8.5</td>
<td>119</td>
</tr>
<tr>
<td>5A1</td>
<td>at 3.8</td>
<td>Buried alluvial soil with charcoal</td>
<td>1.81</td>
<td>8.2</td>
<td>139</td>
</tr>
<tr>
<td>7A1</td>
<td>5.5-7</td>
<td>Basal sloping soil with charcoal dated to 6,140 ± 150 BP</td>
<td>1.72</td>
<td>8.2</td>
<td>131</td>
</tr>
</tbody>
</table>

XRF and XRD analysis of samples

The XRF data indicate calcium (mostly as carbonate) is leached from the upper horizons of the buried soil profiles (A1 and AB horizons) and accumulates in the subsoils or Ck horizons. This is supported by the XRD that shows calcite and smectite are the dominant minerals in the all Ck horizons while smectite is dominant in all topsoil horizons (A1, AB). The slightly reddish brown soil layer 2AB (1.1-1.5m) has the highest K₂O, SiO₂ and Al₂O₃ and this matches with high quartz and plagioclase content supporting the field evidence that this was a separate material. The buried topsoil layers are also higher in silica, aluminium and iron oxides than the C-horizons. This is largely due to the greater carbonate accumulation in the Ck horizons and higher smectite and quartz in the topsoil horizons of the buried soil profiles. Potassium is also higher in all the A and AB horizons of the buried profiles. The data highlight the presence of components of at least five separate soil profiles or soil materials in the upper four meters of the section (each soil material is indicated by a prefix numeral).

The clay mineralogy, as with most materials in this chapter, is dominated by smectite. Calcite only peaks in the calcareous subsoils. Quartz, mica and plagioclase are the
next dominant minerals. As with all soils in the catchment serpentine is also an important mineral. Trace amounts of talc, dolomite and amphibole also occur.

Table 5.23 Major elemental analysis by X-ray fluorescence (%) for site C9

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.2</td>
<td>42.52</td>
<td>0.44</td>
<td>8.44</td>
<td>6.47</td>
<td>0.10</td>
<td>8.43</td>
<td>12.74</td>
<td>0.84</td>
<td>1.48</td>
<td>0.16</td>
<td>18.46</td>
<td>100.08</td>
</tr>
<tr>
<td>0.2-0.5</td>
<td>52.22</td>
<td>0.58</td>
<td>11.55</td>
<td>8.25</td>
<td>0.12</td>
<td>7.14</td>
<td>6.62</td>
<td>1.05</td>
<td>1.90</td>
<td>0.09</td>
<td>10.80</td>
<td>100.32</td>
</tr>
<tr>
<td>0.5-0.8</td>
<td>35.12</td>
<td>0.39</td>
<td>7.74</td>
<td>5.21</td>
<td>0.08</td>
<td>4.35</td>
<td>22.10</td>
<td>0.92</td>
<td>1.33</td>
<td>0.12</td>
<td>22.62</td>
<td>99.98</td>
</tr>
<tr>
<td>0.8-1.1</td>
<td>29.24</td>
<td>0.32</td>
<td>6.18</td>
<td>4.32</td>
<td>0.07</td>
<td>4.02</td>
<td>27.51</td>
<td>0.86</td>
<td>1.09</td>
<td>0.13</td>
<td>26.14</td>
<td>99.87</td>
</tr>
<tr>
<td>1.1-1.5</td>
<td>57.81</td>
<td>0.66</td>
<td>13.35</td>
<td>7.91</td>
<td>0.13</td>
<td>4.84</td>
<td>3.74</td>
<td>1.23</td>
<td>2.18</td>
<td>0.07</td>
<td>8.26</td>
<td>100.18</td>
</tr>
<tr>
<td>1.5-2.0</td>
<td>53.06</td>
<td>0.61</td>
<td>12.54</td>
<td>9.04</td>
<td>0.14</td>
<td>9.06</td>
<td>3.35</td>
<td>1.01</td>
<td>2.19</td>
<td>0.07</td>
<td>8.99</td>
<td>99.98</td>
</tr>
<tr>
<td>2.0-2.3</td>
<td>30.89</td>
<td>0.32</td>
<td>6.49</td>
<td>5.10</td>
<td>0.07</td>
<td>8.06</td>
<td>23.31</td>
<td>0.68</td>
<td>1.11</td>
<td>0.12</td>
<td>23.59</td>
<td>99.74</td>
</tr>
<tr>
<td>2.3-3.6</td>
<td>29.83</td>
<td>0.32</td>
<td>6.34</td>
<td>4.71</td>
<td>0.06</td>
<td>8.08</td>
<td>23.90</td>
<td>0.74</td>
<td>1.12</td>
<td>0.12</td>
<td>24.27</td>
<td>99.49</td>
</tr>
<tr>
<td>3.8</td>
<td>40.48</td>
<td>0.44</td>
<td>8.65</td>
<td>6.31</td>
<td>0.10</td>
<td>8.83</td>
<td>15.01</td>
<td>0.86</td>
<td>1.56</td>
<td>0.12</td>
<td>17.60</td>
<td>99.96</td>
</tr>
<tr>
<td>5.5-7</td>
<td>45.84</td>
<td>0.48</td>
<td>9.85</td>
<td>7.31</td>
<td>0.11</td>
<td>9.21</td>
<td>10.30</td>
<td>0.83</td>
<td>1.72</td>
<td>0.11</td>
<td>14.30</td>
<td>100.06</td>
</tr>
</tbody>
</table>

Table 5.24 Whole soil mineralogy by X-ray diffraction analysis for site C9

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>35-50%</th>
<th>25-35%</th>
<th>15-25%</th>
<th>10-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.2</td>
<td>Smec.</td>
<td>Calcite</td>
<td>Quartz</td>
<td>Plag, Mica, Serp, Chl.</td>
<td>K-feldspar, Dolo, Talc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2-0.5</td>
<td>Smec.</td>
<td>(50-70%)</td>
<td>Quartz</td>
<td>Cal, Mica, Serp, Plag, Chl</td>
<td>K-Feldspar, Dolo, Amph.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5-0.8</td>
<td>Cal, Smec</td>
<td>Quartz</td>
<td>Mica, Chl, Serp, Plag</td>
<td>K-Feldspar, Dolo, Talc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8-1.1</td>
<td>Calcite</td>
<td>Smec.</td>
<td>Quartz</td>
<td>Mica, Qtz, Plag, Chl, Serp</td>
<td>Dolomite, K-Feld, Talc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1-1.5</td>
<td>Smec.</td>
<td>Quartz</td>
<td>Plag.</td>
<td>Mica, Chlorite, K-Feld, Cal, Serp</td>
<td>Talc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5-2.0</td>
<td>Smec.</td>
<td>Quartz</td>
<td>Mica, Serp, Chl, Plag</td>
<td>K-Feld, Calcite, Talc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0-2.3</td>
<td>Smec, Cal</td>
<td>Serp, Qtz, Mica, Chl, Plag</td>
<td>Dolo, K-Feld, Talc, Amph</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3-3.6</td>
<td>Cal, Smec</td>
<td>Mica</td>
<td>Chlorite, Serp, Qtz</td>
<td>Dolo, Plag, K-Feld, Talc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.8</td>
<td>Smecite</td>
<td>Calcite</td>
<td>Mica, Qtz</td>
<td>Serpentine, Chlorite</td>
<td>Plag, Dolo, K-Feld, Talc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5-7</td>
<td>Smec.</td>
<td>Cal., Qtz</td>
<td>Mica, Serp, Chlorite</td>
<td>Plag, K-Feld, Dolo</td>
<td>Talc</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chronology

Charcoal taken from the upper buried black alluvial soil (1.5-2.0m) which caps the fine textured alluvium soil layer has been dated at 8,085 ± 230 cal yr BP (Wk9914).

This age is consistent with the soil profile capping the Syndendron alluvium and correlates well with the dates of 8,050 ±110 years at C17, 7,490 ± 110 years at C11, 9,900 ± 300 years at C12, and 9,350 ± 600 at soil profile P37 (see below). The paleosol at the base of the section, which slopes down to the valley floor, has also been dated and provides a date of 6,140 ± 150 cal yr BP (Wk9912). Clearly one of
the dates is in error. The lower date is suspected based on extensive dating of the Syndendron alluvium at neighbouring sites. Also during sampling this lower site which rests at the base of the section is much more likely to receive fragments of younger charcoal and other debris from the steep exposure above. Although every care was taken in charcoal collection with fragments being removed from in situ with in the soil layers it appears contamination has occurred at this site. The only way to resolve this is to re-run a new sample of charcoal from the site; this was not possible in the current study.

**Discussion and interpretation**

A buried soil (paleosol) at the base of the section can be traced down the valley slope. The soil profile forms on a 31° slope but this decreases to 22° – 18° – 12° and finally 10°. This buried soil shows the paleo-land surface prior to the deposition of the Syndendron alluvium which has since buried the soil by at least 7m and up to >10m of alluvium. The alluvium is composed of inter-beded clayey-silts with some layers of fine gravels-grits. There is one major layer of coarse gravels (see Plate 5.19). The angle of deposition and the form of the modern landscape indicate the alluvial material forms part of a fan. A thin alluvial soil occurs at 3.8 m below the modern surface and indicates a brief hiatus in alluvial deposition. A black buried soil caps the alluvial component of the section and gives an age of 8,085 ± 230 cal yr BP (Wk9914).

The site shows the nature of the Syndendron alluvium and demonstrates it is a valley fill which buries a prior soil covered landscape as seen in sites C6, C12, C13 and below in C19. The soils beneath the alluvium typically contain charcoal rich topsoils indicating fire was a feature of the landscape process between 15 – 11 kyr BP. Several are also mottled suggesting seasonal wetness (C6, C13, and C19) in at least the lower slopes. However the buried soil here is dark brown and free of mottling. This may be due to the moderately steep slope and the position of the site higher in the valley sides.

**Site C19 Syndendron alluvium capping buried soil**

Site C19 is in the mid catchment area near the church of Panagia at latitude 40.1272° N and longitude 21.3754° E. The site shows bedded Syndendron alluvium capping a
buried soil formed on a 18°-26° slope (see Plate 5.23). This buried soil forms in fine textured colluvium and the subsoil rests on bedrock. This buried soil contains much charcoal and has been dated to 14,350 ± 900 cal yr BP (see Figure 5.13, Wk9927). Pictures of the site, the soil materials and the topographic setting are shown in Plate 5.23.

**Field Stratigraphy**

0 – 9 m  C  Fine textured alluvium of silts and fine sands. Beds are 10-15 cm thick and they dip at 8° from horizontal in a down slope direction i.e., toward the stream. Sediments not sampled.

9 – 9.3 m  2A1  Dark greyish brown topsoil horizon with abundant macroscopic charcoal fragments, moderate pedality, soil aggregates contain soft, sub-angular structure, few fine orange mottles, lithic fragments of mudstone suggesting the soil is of colluvial origin, ferruginous coatings (mottle) on some ped faces. These coatings have left plant leaf impressions pressed onto the ped surfaces (see Plate 5.23). The leaf impression within the soil suggests the soil materials have been mixed in some way i.e., soil creep.

9.3 – 9.9 m  2BC  Subsoil horizon of buried soil. Light olive brown, silty clay loam, few fine orange mottles, matrix with angular lithic fragments of mudstone indicating material is of colluvial origin. Weak sub-angular pedality and material lacks stratification i.e. homogenous.

9.9 – 18 m  3R  Mudstone bedrock exposed in isolated pockets but much of the section not visible due to slumping. Presence of bedrock suggests at this site the Syndendron alluvium is deposited against prior valley slopes.
Plate 5.23 Photo A shows section C19 with buried soil layer covered by up to 9 m of fine-textured alluvium with dip of $8^\circ$ toward stream valley indicating they represent fans or slope wash. Soil aggregates contain charcoal fragments and lithic fragments of weathered mudstone. Also shown in upper micrograph (photo B) is iron staining/mottling associated with plant material (scale in mm).

9.0 – 9.5 m 2A1
Buried topsoil with moderate angular pedality, ferruginous cutans on ped surfaces (B), soft 2-10 mm lithic fragments (C), charcoal dated to 14,350 $\pm$ 900 years BP (Wk9927 calibrated)
Atmospheric data from Stuiver et al. (1998); OxCal v3.8 Bronk Ramsey (2002); cub r:4 sd:12 prob usp

14000CalBC 13000CalBC 12000CalBC 11000CalBC

Calibrated date

Radiocarbon determination

Wk9927 (C19) : 11828±70BP

68.2% probability
12110BC (49.2%) 11830BC
11740BC (19.0%) 11610BC

95.4% probability
13300BC (8.4%) 12800BC
12400BC (87.0%) 11500BC

Figure 5.12 Location map of site C19 contours at 4 m intervals

Figure 5.13 Radiocarbon calibration curve for site C19 after Stuiver et al (1998) and software from Bronk Ramsey (2002).
Table 5.25  Field and chemical data for buried topsoil at C19

<table>
<thead>
<tr>
<th>Hor</th>
<th>Description</th>
<th>Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Devel</th>
<th>Ty</th>
<th>Size</th>
<th>React</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A1</td>
<td>Sloping soil material</td>
<td>ZCL+</td>
<td>2.5Y</td>
<td>4</td>
<td>2</td>
<td>AB</td>
<td>20-50mm</td>
<td>1</td>
</tr>
</tbody>
</table>

Discussion and interpretation

The site shows a hill slope paleosol dated in the upper part to 14,350 + 900 cal yr BP that has been buried by thick slope wash and alluvium which is part of the Syndendron alluvium. This site supports the findings of sites C6, C12 and C13 although the date here is a little older. Site C13 is higher up slope and represents the continuing erosion and transport of sediment on the adjacent slopes while this site is buried by the alluvium. The site is also similar to site C6 where a charcoal rich soil is buried by Syndendron alluvium and is dated to a similar time i.e., 14,750 ± 1000 cal yr BP at C6. Site C19 helps provide a lower maximum age for the Syndendron alluvium than C6.

This site also demonstrates landscape fires were occurring in the mid catchment area between 15 – 11 kry BP. The other sites demonstrating fire in this period include C6, C9, C12, and C13.

The paleosol at C19 has mottling patterns in the soil profile and the subsoil is light olive brown. Both suggest the soil may be seasonally waterlogged for brief periods. Other late glacial soils have also demonstrated such waterlogging features i.e., C6 and C13. They suggest greater seasonal wetness at the time, whether this is associated with greater seasonality during the glacial stadials (Macklin et al. 1995; Ariztegui et al. 2000) or whether it is to do with the late glacial climatic optimum (Bolling – Allerod interstadial) cannot be fully determined. However the timing of the later makes it a distinct possibility.

Review of site P37 Paleosols on Syndendron alluvium

A re-examination of soil profile P37 (see Appendix 2) was undertaken during the current study as the site provided the only radiocarbon date associated within the 10 –
11 m Syndendron alluvium deposit described by Doyle (1990). Recent erosion at the site has provided evidence of human occupation on the buried alluvial paleosol at the site. The lower buried soil was dated at 9,350 ± 600 cal yr BP (see Figure 5.14, Wk1485). The fine textured alluvial soil contains irregular groupings of sub-angular and sub-rounded stones (see Plate 5.26). One of these stones is highly rounded and pitted at one end, which suggests it may have been used for striking. The stone is broken in an unusual concave manner at one end (see Plate 5.27). This has been identified by Eleni Pauagopoupou of the Archaeology Ephoria in Athens as a grinding stone and indicates Mesolithic or Aceramic Early Neolithic people inhabited the valley. The alluvial paleosol at P37 was traced along the section and around a protruding part of the section to where a fire-hearth can be seen formed on the paleosol surface (see Plate 5.28). An unusual oblong block of pressed soil (2 x 2 x 8 cm) was also associated with the paleosol. This soil block was coated with calcium carbonate and stood out clearly from the surrounding soil matrix (see Plate 5.27 and Figure 5.16). The origin of this soil block is not known but it was clearly at odds with the remainder of the soil materials and may be anthropogenic. However the grinding stone and other stones in the fine textured soil, together with the fire-hearth evidence indicate humans were using the area at about 9.4 cal kyr BP. The site also indicates the use of fire at this time. Such a finding is not unexpected as Upper Palaeolithic tools have been found at Syndendron and over half a dozen other sites in the Nomos of Grevena (Wilkie and Savina 1992). Also nearly 20 Early Neolithic sites have been identified in Grevena (Wilkie and Savina 1997).

The distinct 9.4 kyr BP paleosol which caps the Syndendron alluvium forms on a gentle slope and its thickness varies down slope. It also has an abrupt lower boundary on to the underlying alluvium. All these factors suggest the material forming the paleosol may be largely colluvial in origin. It has a silty clay loam matrix but in some parts of the section contains stones floating in this fine matrix (see Appendix 2). This also supports the notion of a colluvial origin. Thus although it appears well-developed the paleosol is likely to be transported pedogenic material from adjacent slopes. Thus it does not represent a major hiatus. The abrupt increase in alluvial sedimentation above this paleosol represents the last phase of alluvial deposition associated with the Syndendron event – here termed the Syndendron B Alluvium. The sediment for Syndendron B is probably derived from re-incision and reworking.
of Syndendron A alluvium from further up the valley. Note this site (P37) is in the lower part of the catchment and would be the last to re-incise.

**Summary of field stratigraphy**

In the upper part of the section up to one metre of dark, cracking silty clay soil caps the section. This modern soil has been leached of carbonate in its upper part and has highly calcareous subsoil (see Appendix 2, P37). The substrate appears to be either slope wash or alluvium as it is fine-textured and contains no visible angular or sub-angular coarse fragments that might suggest the material is colluvial in nature. However, it does not exhibit bedding or stratification but this may be due to the accumulation of much calcium carbonate. A thin paleosol with dark silty clay loam topsoil has formed in fine stratified alluvial sediments between 1.6 - 2.2 m. This caps a very distinct dark paleosol dated to 9.4 cal kyr BP which occurs at 2.2 to 3.2 m. This dark paleosol has strong prismatic to blocky structure. The paleosol overlies up to six metres of stratified fine textured alluvium. The distinct bedding of fine textured alluvium extends to the base of the visible part of the section. An animal burrow (fox hole) has exposed coarser sediment, namely fine gravels (2-6 mm), at the base of the section. In some parts of the section alluvial fine gravels, which are clast-supported, occur below the modern topsoil suggesting alluvial or slope wash processes.

**Discussion and interpretation**

The section represents the Syndendron A & B alluvial aggradation in the lower catchment. The dated soil capping the Syndendron B alluvium indicates a late stage deposition occurred after 9.4 cal kyr BP. Alluvial aggradation of fine gravels and sands occurs at the base of section indicating possible stream channel type deposition. This fine gravelly alluvium is capped by bedded finer textured (sandy and silty) alluvium with lenses and beds of fine gravels (2-4 cm thick). This indicates finer over-bank type deposits dominated the mid-upper section. Two paleosols can be seen capping the alluvium. The lower more prominent of the two is a well-structured, dark soil leached of carbonate in its upper part. It has been radiocarbon dated using fragments of charcoal in the topsoil to 9.4 cal kyr BP. It appears this well structured buried soil was also an occupation layer as rounded and broken stones appear in clusters embedded in the fine soil matrix and a fire pit is also located on the soil in an adjacent section. This distinct soil was buried by either Syndendron B alluvium
Plate 5.24 Plate from Doyle (1990) showing the buried soils at P37 which occurs below the village of Mega Sirini in the lower catchment (see Figure 5.6). The distinct buried paleosol is dated to 9,350 ± 600 calendar years BP (calibrated Wk1485). Above the key stratigraphic units are marked. (small spade measures 80 cm).

Figure 5.14 Radiocarbon calibration curve for soil profile P37 after Stuiver et al (1998) and software from Bronk Ramsey (2002).
Figure 5.15 Location and topography at site P37 from Doyle (1990). Also marked is section S7A and S7B from Doyle (1990) for which palaeomagnetism data presented in chapter 5 with. Contour internals are 4 m.

Plate 5.25 View of the P37 site show adjoining slope and stream. Plate also show location of fire pit see in buried alluvial soil.
Plate 5.26 Re-examination of Syndendron alluvium in lower catchment at site P37. The main buried soil at P37 has an unusual “grouping” of rounded stones in an otherwise fine textured alluvial material. An odd broken stone was also found in this layer (see above left and Plate 5.25). The dark paleosol is dated to 9,350 ± 600 (calibrated Wk1485). The dark brown paleosol is then capped by more fine textured alluvium. Photo B shows location of stone, later identified as a grinding stone by Eleni Pauagopoupou (pers comm., 2004). Photo C shows close up of stones in soil layer.
Plate 5.27  A) - an unusual stone which occurs in the buried soil dated to 9,725 ± 475 (calibrated Wk1485) at P37. The soil matrix and underlying material are fine-textured. Thus it is very unusual to have a stone in such a fine alluvial material. Also the stone is associated with a soil surface which humans were probably living. A second feature is the stone is broken at one end. Such an unusual break would be difficult to achieve naturally – the stone has thus been identified as a grinding stone and confirmed by Eleni Pauagopoupou of Archaeological Ephoria in Athens pers comm., 2004). B) An unusual “soil block” of compacted soil with distinct outer coating of brown clay, then calcium carbonate and then mixed matrix (see Figure 5.16. The internal matrix is olive yellow soil and has vein carbonate.

Plate 5.28  Approximately 30-50 m along the P37 section a buried soil which caps the Syndendron alluvium has a burnt area which may well be an anthropogenic fire pit or hearth. This feature in combination with the collection of stones and the identified grinding stone (above) indicate people were at the site at or after 9.3 Ka BP. Following this further alluvial sedimentation and soil formation occurred at the site prior to soil colluvium burying the site.
Figure 5.16  ESEM spectra for the unusual “soil block” found in the 9.3 kry BP buried soil at P37 (also see Plate 5.27-B). Graph a) shows the external clay coating on “soil block” with high silica, magnesium and aluminum indicating smectite, but the potassium spike also indicating mica as shown by Doyle (1990) in the soil profile, Graph b) shows the distinct calcium carbonate coating over the “soil block” and Graph c) shows a calcium carbonate vein lining a pore.
of sometime after 9.4 cal kyr BP. A thin soil formed on this alluvium but appears to
have been truncated and buried by pedogenic colluvium in the early Holocene.

**Site C20 Tsifliki – Syndendron alluvium covered by colluvium**

Site C20 is located 200 m SE of Tsifliki in the upper catchment at latitude 40.1389°
and longitude 21.3570° (see Figure 5.8 and Plate 5.28). Despite the site being
composed of 2-3 m of stratified soil colluvium overlying the Syndendron alluvium a
lack of charcoal in the section meant there was no opportunity for radiocarbon dating.
This site provides another example of how moderately thick soil colluvium caps the
Syndendron alluvium in most parts of the valley. The colluvial materials appear to
have been deposited in a series of shallow earthy deposits separated by stone-lines.
No distinct paleosol has formed on the Syndendron alluvium as has occurred at sites
lower in the catchment e.g., C6, C17, P37.

**Summary of Syndendron alluvial sites**

The Syndendron alluvium, associated slope deposits and underlying paleosols have
been comprehensively dated and described in the upper and mid-catchment. Further
work in the lower catchment would help improve the chronology but suitable
exposures were not located.

The Syndendron alluvium is a substantial largely fine textured, well stratified
aggradation deposit that appears to have been derived from slope wash and some
debris flow deposits. The upper slopes of the valley sides appear to be an important
source area, particularly in the upper and mid catchments. The Syndendron sediment
forms alluvial fans in the upper and mid catchment while in the mid to lower
catchment an alluvial terrace has developed. The alluvium is capped by soil
colluvium derived from the valley sides.

The Syndendron sediment buries paleosols dated using charcoal at 11.0, 12.3, 14.3
and 14.8 cal kyr BP. The alluvium itself is dated using charcoal within the sediment
at 11.8 and 14.2 cal kyr BP in the upper and mid catchments. The older date of 14.2
at the base of site C17 may represent entrained old charcoal. Buried soils, which form
above the alluvium, have been dated to 8.0, 8.1, 9.4 and 9.9 cal kyr BP and indicate
the alluvial aggradation was complete by the very early Holocene. Following the
Plate 5.29 Site C20 shows a site which lies 200m SE of the Tsifliki settlement. The section is composed of multi-layered, brown and dark brown soil-derived colluvia. The soil-derived colluvia abruptly overlie fine-textured alluvium (light grey). This sequence is very similar to the nearby site C11 (200 m upstream, see Figure 5.8) where the soil colluvium is dated at it’s base at 5.0 kyr BP and the underlying alluvium contains charcoal dated at 11.8 kyr BP.
deposition of the Syndendron B alluvium, soil creep and soil development on the surface occurred. The stream and tributaries appear to have re-incised the valley, probably due to a decrease in sediment supply following the increased forest cover in the Holocene (Wijmstra et al. 1990; Willis 1992a; Tzedakis 1993; Turner and Sanchez-Goni 1997; Willis 1997). The early Holocene was also wetter, aiding stream incision (Wijmstra et al. 1990; Ariztegui et al. 2000; Kallel et al. 2000). The incision appears to have been completed by 7.5 kyr in the upper catchment because a debris flow deposit reaches the bedrock lined valley floor at this time (C11). This incision, and particularly slope undercutting, may have continued until 6.6 kyr BP. This is because a debris flow deposit, containing large intact blocks of reddish brown soil, is located only five metres above the valley floor at site C1 at this time (see Chapter 7).

Climatic fluctuations cannot be ruled out as a cause of the Syndendron alluvial aggradation as large fluctuations were occurring in the late glacial period (Chappellaz et al. 1993; Mayewski et al. 1993; Tzedakis 1993; Turner and Sanchez-Goni 1997; Ariztegui et al. 2000; Woodward and Goldberg 2001; Mithen 2003; Wick et al. 2003). However, this may have been aided by frequent fires in the landscape as shown by many sites in the Leipsokouki valley (C6, C9, C11, C12, C13 and C19). At all sites where soil profiles were visible under the alluvium an abundance of fragmentary charcoal was found in the soils. In some sites, such as C13, C6 and C9 the charcoal rich paleosols can be traced over 20-100 m indicating extensive fires occurred in the catchment at the time. At site C13 loose, highly calcareous, ashy material occurs on, and is partly incorporated within, the topsoil of a paleosol. This loose ashy layer has been buried by fine textured slope wash. This would suggest the fire, and associated loss of vegetative cover, was rapidly followed by hill slope erosion that buried the lower valley slopes with alluvial materials e.g., sites C6 and C13. The causes of the fires at these times (15-11 kyr BP) are not known. Both natural and human induced fires are possibilities. However the presence of Upper Palaeolithic archeologically materials in the catchment and the general absence of charcoal in older sedimentary materials (Chapter 4) would suggest humans are a likely cause of the burning. Palaeolithic man was a great user of fire (De Lumley 1969) (Gowelett et al. 1981; Goudie 1993). The onset of the late glacial interstadial (14.5 - 12.7 kyr BP) may lead to use of fire to control the expansion of oak wood. Changes from open steppe to forested vegetation would limit hunting visibility,
possibly reduce game and encourage more regular firing of the landscape. Fires serve
the dual purpose of attracting game and reducing any increase in tree cover (Mellars
1976; Gowelett et al. 1981; Clark and Harris 1985). Site C13 (12.3 cal kyr BP)
indicates a mixture of trees and grasses while site C19 (14.4 cal kyr BP) indicate
grasses were present along with charcoal fragments of >3 mm dia., also suggesting
the presence of woody plants.

Examination of sedimentation rates for the Syndendron A alluvium provides
remarkably consistent results. Three alluvial sections have two or more radiocarbon
dates while five others have an upper or lower date that can be used to get a
reasonable estimate of sedimentation rates. By using the mean of the upper and the
mean of the lower dates a table of eight sedimentation rates was determined (Table
5.26).

<table>
<thead>
<tr>
<th>Site</th>
<th>Thickness of alluvium (m)</th>
<th>Start time (kyr)</th>
<th>End time (kyr)</th>
<th>Period of deposition (kyr)</th>
<th>Sedimentation rate (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C17</td>
<td>7</td>
<td>14.2</td>
<td>8.08</td>
<td>6.12</td>
<td>1.1</td>
</tr>
<tr>
<td>C12</td>
<td>1.6</td>
<td>10.96</td>
<td>9.9</td>
<td>1.06</td>
<td>1.5</td>
</tr>
<tr>
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<td>11.8</td>
<td>7.49</td>
<td>4.31</td>
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<td>12.8</td>
<td>8.08</td>
<td>4.72</td>
<td>1.7</td>
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<tr>
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<td>12.8</td>
<td>9.4</td>
<td>3.5</td>
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</tr>
<tr>
<td>C13</td>
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<td>12.25</td>
<td>8.8</td>
<td>3.45</td>
<td>1.4</td>
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<td>14.75</td>
<td>8.8</td>
<td>5.95</td>
<td>1.3</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>12.8</td>
<td>8.8</td>
<td></td>
<td>1.4</td>
</tr>
</tbody>
</table>

The sedimentation rates of the sections are quite similar (mean of 1.4 mm/yr). The
two exceptions are the upper and lower catchment sites (C11 and P37) which may
represent under and over estimates respectively. The low rate in the upper catchment
probably relates to erosion of part of the alluvial section prior to burial (especially
when the height of the alluvium at C11 is compared to C12 only 100 m upstream.
Site C12 has Syndendron alluvium deposited on the valley side approximately 13-14
m above modern stream level while C11 is in the valley floor. The higher rate of
sedimentation in the lower catchment reflects the reduced stream gradient and wider
valley floor leading to a more depositional environment. This is reflected in the fact
at P37 a second phase of Syndendron alluvium is deposited after 9.4 cal kyr, burying
a prominent paleosol (Syndendron B). These two sites, C11 and P37 indicate the
different environments in the upper and lower catchments, one higher energy
involving rapid deposition and re-incision, while the other lower energy leading to longer periods of aggradation. The fact this late stage deposition at P37 occurred in the moister Holocene period when tree cover was becoming established points to the very important role of fire as a causal factor in the erosion and deposition history at this time. The presence of grinding stones, fire pits along with other artefacts found in the 9.4 kyr BP paleosol at P37 supports this notion of anthropogenic disturbance.

The mean sedimentation rate for the Syndendron alluvium of 1.4 mm/yr is probably a slight under estimate; this is indicated by taking the strictest reasonable limits on the start of sedimentation period of 12.25 kyr (C13) and applying this to P37 instead of the mean maximum date. This gives a maximum sedimentation rate of 2.7 mm/yr for the Syndendron alluvium.
CHAPTER 6  Holocene alluvial deposits and soils

Introduction

This chapter presents data characterising the nature and age of three Holocene alluvial deposits and the associated soil materials. These deposits represent three or perhaps four phases of alluvial aggradations namely the Amygdalies, Sirini (A and B) and the Leipsokouki deposits. They are discussed here from oldest to youngest.

Amygdalies Alluvium

Site C8 mid Holocene alluvial deposit

Introduction and location

Section C8 is located at latitude 40.1077° and longitude 21.4492° in the lower reaches of the Amygdalitikos stream close to its confluence with the Leipsokouki stream (see Figure 6.1 and Plates 6.1 - 6.2). The site is at the base of a steep slope (25°-30°) and forms part of a gentle colluvial fan sloping at 8°-10°. The section, which is composed of alluvial sediment capped by colluvial material, is inset into the lower Plio-Pleistocene sediments (Plate 6.4). The alluvial sediments have several thin soil profiles developed within them. The base of the alluvium and the topsoil horizons of the three alluvial soils have been dated. One of the colluvial layers was also dated.

Field Stratigraphy and microscopy

0-0.3 m  1A1  Non-calcareous, gravelly loamy sand forming modern soil and appears to be derived from reddish brown colluvium derived from adjacent slope (angle of 25°-30°). Very weak structure grading to single grained.

0.3 – 0.4 m  2ABk  Calcareous sandy light clay with gravel stringers that dip into the slope suggesting the material is dominantly alluvial (marked on Plate 6.1). Matrix has moderate polyhedral structure, charcoal sample dated to 4,375 ± 525 cal yr BP (see Figure 6.2, Wk9818).

0.40 – 0.65 m  2B2k  Calcareous sandy light clay matrix with gravel stringers that dip into the slope suggesting the material is dominantly alluvial (see Plate 6.1). However the rounded
stones in the soil appear to be sourced from adjacent hill slope.

0.65 – 0.85 m  3A1  Distinct dark topsoil type horizon with well developed structure, silty light clay texture, interpreted as fine alluvial soil based on texture and lack of coarse fragments, charcoal sample provided a calibrated date of 4,675 ± 155 cal yr BP (see Figure 6.2, Wk9911).

0.85 – 1.25 m  3BCk  Subsoil horizon of buried alluvial topsoil above fine sandy loam texture, contains distinct calcium carbonate precipitation in tubular (root) pores, moderately well developed structure interpreted as fine sandy alluvium.

1.25 – 1.45 m  4A1  Dark topsoil horizon with strong fine polyhedral structure formed in fine-textured alluvium, thin 1-2 mm calcium carbonate coatings lining pores. Charcoal sampled from lower part of layer provided a date of 5,300 ± 450 cal yr BP (see Figure 6.2, Wk9910)

1.45 – 1.55 m  4BC  Distinct stone-line in-filled with soil-like matrix, forms the subsoil of the buried topsoil above. There is a very regular line of similar sized rounded, and some angular, river stones (see Plate 6.2). The stone-line may be anthropogenic; however the material lacks Neolithic pot sherds that might support this notion.

1.55 – 1.9 m  4C1  Loamy sand fine-textured, bedded alluvium of over-bank type deposits.

1.9 – 2.4  4C2  Loose, sorted, alluvial sand probably overbank or levee deposits. Charcoal taken from 2.0-2.3 m provided a date of 5,875 ± 425 BP (Wk9817).

2.4 – 3.1 m  4C3  Well sorted, clast-supported, alluvial gravels suggesting they are reworked Plio-Pleistocene gravels which underlie the section.

3.1 m+  5D  In situ Plio-Pleistocene gravels.

The stratigraphy identified in the field is supported by morphological assessment of samples. All the buried topsoil horizons (A1 and AB types) have moderate to strong
Plate 6.1 Site C8 showing colluvial-soil facies grading to alluvial-soil facies. At this site four samples of charcoal were taken for dating to highlight the progressive nature of this sediment accumulation and soil formation (white arrows = charcoal samples). White dashed line separates colluvial and alluvial materials while the black dashed lines trace the continuity of topsoil layers across the different materials and the thin black lines show the orientation of stone-lines (stringers) in the alluvial sediment. Note they all dip into the colluvial section.

Figure 6.1 Location of site C8 (4 m contour interval). Also refer to figure 6.2 for more general location with respect to Grevena township.
Plate 6.2 Photo A shows close-up view of site C8 with stony reddish brown colluvial soil capping alluvium with two distinct topsoil layers. Four charcoal samples radiocarbon dated (white arrows). Photo B below shows how the alluvium and colluvium are inset into Plio-Pleistocene sediments.

a) Non-calcareous coarse reddish brown colluvium (0-0.3m) caps fine-textured calcareous alluvium dated in upper part (0.3-0.4 m) at 4,375 ± 525 BP (calibrated Wk9818)

b) Buried fine-textured, calcareous alluvial topsoil dated in upper part (0.8m) at 4,675 ± 155 BP (calibrated Wk9911)

c) Buried fine-textured calcareous alluvial topsoil (1.3-1.45 m) dated at 5,300 ± 450 BP (calibrated Wk9910)

d) Loose sandy alluvium charcoal from 2.0-2.3 m dated to 5,875 ± 425 BP (calibrated Wk9817)

e) Gravelly alluvium – not dated
structural development. The topsoil horizons also have darker soil colours while the lower two alluvial topsoils have slightly heavier field textures than their respective subsoil horizons. Also it can be seen from Plate 6.1 that the soil horizons of the alluvial soils grade laterally into the stony colluvial soils. The dashed white line on Plate 6.1 marks the approximate break in materials (colluvial – alluvial) but the topsoil horizons, marked with dashed black lines, can be seen to cut across the different material indicating the continuity of the soil profile across a change in parent material. Such a phenomena was termed “continuity over diversity” by Butler (1959).

The stoniness of some of the alluvial soils is not unexpected as the topsoil layers represent a longer time interval than the underlying alluvial layers, which may aggrade quite rapidly. Thus the alluvial soil surface would be exposed for sufficient time to allow colluvium to creep down slope and merge with the alluvial topsoils. Evidence is provided by stone stringers which dip into the adjacent hill slope, the calcareous nature of the sediment and its fine texture helps separate the alluvial sediment from the non-calcareous very gravelly and coarser textured colluvial materials. Also the gravels and stones in the colluvial sediments are commonly oriented so as to dip down the natural slope (see Plates 6.1 and 6.2). Thus the orientation of the gravels and stones indicates whether they are likely to be part of a colluvial body of material moving down slope or simply odd stones that have rolled down slope and come to rest on a sub-horizontal terrace surface.

Table 6.1 Basic field morphological data for soil site C8

<table>
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<tr>
<th>Depth (m)</th>
<th>Hor</th>
<th>Description</th>
<th>Text</th>
<th>Moist Description</th>
<th>Color</th>
<th>Dry</th>
<th>Moist Color</th>
<th>Dry Description</th>
<th>Structure</th>
<th>Dev</th>
<th>Ty</th>
<th>Size</th>
<th>React</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.3</td>
<td>1A1</td>
<td>Modern colluvial soil</td>
<td>CLS</td>
<td>10YR 3 3</td>
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<td>10YR 3 3</td>
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<td>SG</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.3-0.4</td>
<td>2ABk</td>
<td>Buried topsoil with charcoal</td>
<td>SLC</td>
<td>10YR 3 2</td>
<td>2</td>
<td>10YR 4 2</td>
<td>2</td>
<td>PO 2-5mm</td>
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<td>0.40-0.65</td>
<td>2B2</td>
<td>Buried subsoil (alluvium)</td>
<td>SLC</td>
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<td>2</td>
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<td>Buried alluvial soil – topsoil</td>
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<td>2</td>
<td>1Y 4 2</td>
<td>3</td>
<td>PO 5-10mm</td>
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<td>0.85-1.25</td>
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<td>Buried alluvial soil – topsoil</td>
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<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1.6-1.85</td>
<td>4BC</td>
<td>Buried alluvial soil - subsoil</td>
<td>SCL</td>
<td>2.5Y 4 3</td>
<td>2</td>
<td>2.5Y 6 3</td>
<td>0.5</td>
<td>SB 5-10mm</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Soil analytical data

The data in Table 6.2 show the higher levels of organic carbon values generally support the field-identification of the various topsoil layers (A1 and AB types). The two lower alluvial topsoils have lower pH values than their underlying subsoil
horizons as well as being of darker Munsell colour (Table 6.1). The lower pH values in these topsoils is likely to be a factor of the accumulation of organic matter but may also be partly due to leaching of some or all of the carbonates. The electrical conductivity values (EC 1:5 soil:water) are a little higher in the two lower alluvial topsoil horizons. However the electrical conductivity values are generally very low throughout the profile and are a result of the good drainage characteristics of this section and generally low salinity environment.

**Table 6.2 Basic soil chemical data for soil site C8**

<table>
<thead>
<tr>
<th>Horiz</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC mS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A1</td>
<td>0-0.3</td>
<td>Modern colluvial soil</td>
<td>1.43</td>
<td>7.1</td>
<td>152</td>
</tr>
<tr>
<td>2ABk</td>
<td>0.3-0.4</td>
<td>Buried topsoil with charcoal</td>
<td>0.56</td>
<td>8.1</td>
<td>136</td>
</tr>
<tr>
<td>2B2</td>
<td>0.40-0.65</td>
<td>Buried subsoil (alluvium)</td>
<td>0.98</td>
<td>7.9</td>
<td>166</td>
</tr>
<tr>
<td>3A1</td>
<td>0.65-0.85</td>
<td>Buried alluvial soil – topsoil</td>
<td>0.92</td>
<td>8.0</td>
<td>164</td>
</tr>
<tr>
<td>3BC</td>
<td>0.85-1.25</td>
<td>Buried alluvial soil – subsoil</td>
<td>0.37</td>
<td>8.3</td>
<td>147</td>
</tr>
<tr>
<td>4A1</td>
<td>1.25-1.45</td>
<td>Buried alluvial soil – topsoil</td>
<td>0.82</td>
<td>8.1</td>
<td>176</td>
</tr>
<tr>
<td>4BC</td>
<td>1.6-1.85</td>
<td>Buried alluvial soil - subsoil</td>
<td>0.20</td>
<td>8.4</td>
<td>101</td>
</tr>
</tbody>
</table>

**Chronology**

Charcoal samples were taken from four depths in the section. The upper-most date was on the contact (0.3-0.4 m) of the upper colluvial soil materials and the first of three buried alluvial soils and gave a date of 4,375 ± 525 BP (Wk9818). A second alluvial topsoil (3A1) was dated at a depth of 0.8 m and gave an age of 4,675 ± 155 BP (calibrated date Wk9911). The lower of the alluvial topsoil (4A1) was dated at a depth of 1.3-1.45m and gave an age of 5,300 ± 450 BP (calibrated Wk9910).

Charcoal from the alluvium near the base of the section, at 2-2.3 m, just above the contact with the Plio-Pleistocene sediments was dated at 5,875 ± 425 BP (calibrated date Wk9817). The striking thing with this site is the very narrow range of dates on the deposit. The whole section represents approximately 1,500 years in duration from top to bottom. This appears to have provided sufficient time for the formation of two distinct alluvial topsoil layers and the deposition of 3 m of alluvial sediment and up to 3 m of colluvial sediment.
Figure 6.2 Radiocarbon calibration curves for site C8a-d after Stuiver et al. (1998) and software from Bronk Ramsey (2002).
0 – 0.3 m 1A1
Non-calcareous, modern topsoil, rounded and broken fragments, poor sorting (A and B) indicate colluvial nature of soil materials, sandy texture

0.3 – 0.4 m 2ABk
Calcareous fine texture with gravel stringers. The dominantly rounded and moderately well sorted fragments suggests an alluvial source (A). Much calcium carbonate precipitated in pores of mod. develo.p. peds (B)

0.4 – 0.65 m 2B2k
Calcareous fine-textured matrix with both rounded and some broken gravel fragments indicate a local source (A), moderate angular pedality (B)

0.65 – 0.8 m 3A1
Calcareous topsoil layer with strong angular pedality, appears to be derived from alluvium as material lacks coarse fragments although gravel stringers occur in section, calcium carbonate in precipitated in pores

Plate 6.3 Micrographs of site C8 soil materials (scale in mm).
**0.9 - 1.25 m 3BC**
Sandy matrix with no coarse fragments, distinct soft calcium carbonate coatings deposited in pores

**1.25 - 1.5 m 4A1**
Topsoil layer with moderate pedality, distinct carbonate coatings lining pores, sub-angular lithic fragments and charcoal in soil matrix

**1.65 - 1.85m 4C1**
Subsoil horizon, weak pedality, distinct carbonate coatings lining pores and cracks, well sorted sandy texture, no coarse fragments suggest material is alluvial

*Plate 6.3 Continued C8 soil materials (scale in mm).*
Plate 6.4 Photo A shows a well developed paleosol with strongly developed calcic horizon buried within the Plio-Pleistocene sediments in the lower catchment of the Leipsokouki valley. Section is immediately adjacent to site C8. Photo C shows calcium carbonate nodules up to 10 cm in diameter indicating considerable age to paleosol. Section is buried by over 60 m of Plio-Pleistocene sediment. Photo B shows close up of paleosol and overlying Plio-Pleistocene gravels.
Discussion and interpretation

Section C8 indicates the Amygdalietikos tributary had incised into the Plio-Pleistocene deposits prior to 6 kyr BP. This supports the findings in the upper catchment at C11 that indicated streams were incised at 7.4 kyr BP. This initial incision was followed by deposition of a 0.7 m layer of water-worn gravels indicating reworking of the Plio-Pleistocene gravels during the stream incision. These gravels are overlain by 1.0 m of loose sand and silt dated at 5.9 cal kyr BP and interpreted as over bank type deposits. This alluvium is capped by a distinct line of rounded stones. Alluvial deposition continued until 5.3 cal kyr BP with approximately 0.2 m of fine-textured alluvium being deposited on the stone-line. A distinct dark topsoil (4A1) developed on the alluvium at about 5.3 cal kyr BP and it can be seen to extend laterally and then upslope onto hill slope colluvium (see Plate 6.1). The soil layer indicates somewhat stable conditions at the site. Further deposition of 0.5 m of fine textured alluvium then buried this soil layer. The source of the alluvium was partly slope deposits as colluvium from the surrounding slopes grades into the alluvial facies near the base of the slope (see Plate 6.1 and Figure 6.1). A second distinct alluvial topsoil (3A1) formed at about 4.7 cal kyr BP on the second phase of alluvium. This soil also appears to grade laterally into the slope deposits.

Section C8 demonstrates the Amygdalies alluvium was deposited in a series of events separated by soil formation. During the 600 years that separates the two lower buried soils in the section, 0.5 m of alluvium was deposited giving a sedimentation rate of 1 mm/yr. The rate of alluvial and colluvial deposition then accelerates with up to 0.8 m of alluvium (only 0.45 in measured part of section however), which appears to be derived from re-working of associated colluvium, being deposited before 4.38 cal kyr BP. Thus 0.8 m of alluvium and up to 1.5 m of colluvium appears to have been deposited in approximately 300 years. However the calculated rate given in Table 6.3 below is based on the measured part of the section. If measured at the thickest part the rate increases to 2 mm/yr. The sedimentation rate for the post 4.38 cal kyr BP deposit is likely to be very high as about 1.4 m of colluvium caps the site (see Plate 6.1) but no dating of the modern land surface has been undertaken.
Table 6.3  Sedimentation rates for site C8 (Amygdalies alluvium)

<table>
<thead>
<tr>
<th>Site</th>
<th>Thickness of alluvium (m)</th>
<th>Start time (kyr)</th>
<th>End time (kyr)</th>
<th>Period of deposition (kyr)</th>
<th>Sedimentation rate (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C8 upper</td>
<td>0.45</td>
<td>4.68</td>
<td>4.38</td>
<td>0.31</td>
<td>1.5</td>
</tr>
<tr>
<td>C8 mid</td>
<td>0.6</td>
<td>5.30</td>
<td>4.68</td>
<td>0.61</td>
<td>1.0</td>
</tr>
<tr>
<td>C8 base</td>
<td>0.7</td>
<td>5.88</td>
<td>5.30</td>
<td>0.58</td>
<td>1.2</td>
</tr>
<tr>
<td>C8 Total</td>
<td>1.75</td>
<td>5.88</td>
<td>4.375</td>
<td>1.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

The alluvium in the section is generally fine-textured and calcareous. The alluvium represents the deposition of sediment eroded both locally and from further up the catchment. Initially this erosion must have been quite mild; as the surrounding steep slopes did not supply much gravel to cap the soils, however after 4.7 cal kyr BP the alluvial accumulation and the colluvial deposition accelerate. The lower two alluvial topsoils are moderately well developed and support the idea that shorter periods of landscape stability and soil formation were replaced by more aggressive erosion and deposition, especially after 4.7 kyr BP.

Overall this section demonstrates the close relationship between hill slope erosion and alluvial aggradation. It would appear that valley-wide aggradation occurred in the period between about 6 cal kyr BP and 4.7 cal kyr BP. The next period of major erosion and deposition occurred after 4.7 cal kyr BP and before 4.3 cal kyr BP, i.e., during the Early Bronze Age, and this appears to be supplied from local hill slope erosion. This may reflect an increase in local grazing pressure and clearance of the slopes above the site. The hill slope erosion seems to continue as the site becomes buried by over 2 m of gravelly colluvium after 4.3 cal kyr BP.

**Sirini alluvium**

The Sirini alluvium was first defined by Doyle (1990) using a single radiocarbon date taken at 6.5 m from the surface of a 9.6 m thick alluvial fill. The date provided a calibrated age of 2,450 \(\pm\) 300 cal yr BP (Wk 1579) at site P52 (Doyle 1990). The present study has attempted to gain a more detailed chronological control using charcoal samples from the base and upper part of the Sirini alluvium to help determine sedimentation rates. Several sites have been sampled and dated and the results are presented here i.e., C4, C3, C2, and C14. They indicate the aggradation.
occurred in two parts, the lower Sirini A alluvium and the upper Sirini B alluvium. The two Sirini units are separated by a period of soil formation.

**Site C4 Sirini alluvium**

*Introduction and location*

This site is located in the lower catchment, an area where the Plio-Pleistocene sediments form the underlying bedrock materials. The site is 400 m upstream of the confluence with the Amygdalitikos tributary stream at latitude 40.100° N and longitude 21.440° E (see Figures 6.2 and 6.4). Two charcoal samples were taken, one from near the top of the section and a second near the base of the alluvial section. The site provides an excellent opportunity to determine the onset of alluvial aggradation, at this location and also the secession of aggradation.

*Field stratigraphy and microscopy*

The field stratigraphy indicates that several depositional and soil-forming cycles have occurred at this site. However the stratigraphy is not quite as complete as sections C14 or C3 and thus some earlier parts of the Sirini alluviation may not be represented at this site. Details of soil colour, structure and texture are provided in Table 6.4, additional notes and observations on the materials are provided below and in Plate 6.5.

0 - 0.1 m 1A1 Clay loam with weak sub-angular pedality. Matrix contains angular (broken) gravel lithic fragments (2-10 mm) indicating it is of colluvial origin. Matrix is non-calcareous.

0.1 – 0.6 m 1B2 Gravelly, brown, light clay, lithic fragments (1-20 mm) are rounded and angular indicating this B2 horizon is of colluvial derived materials. Matrix is non-calcareous.

0.6 - 0.8m 1C Stone-line of large rounded cobbles (10-100 mm) set in gritty sandy matrix. The presence of this distinct stone-line supports the notion the upper modern soil is composed of colluvial material or slope deposits. The coarse fragments float in a finer matrix i.e., they are not clast-supported as is typical of water transported deposits. Thus they are likely to be slope
deposits derived from erosion of the Plio-Pleistocene materials which contain rounded cobbles.

0.8 – 1.0 m  2A1  1st buried topsoil horizon with dark colour and strong polyhedral pedality and a few sub-rounded and sub-angular lithic fragments (2-15 mm) which suggest the material is a slope deposit - charcoal was extracted for radiocarbon dating from the buried soil at 90 cm. The calibrated age is 2,010 ± 140 cal yr BP (WK9815). Material is non-calcareous.

1.0-1.2 m  2B1  Light olive brown subsoil horizon of 1st buried soil. The silty light clay matrix has a few rounded lithic fragments (1-20 mm) present suggesting the materials may be water sorted slope wash or stream sediment i.e., over bank deposits. The broad size range suggests slope wash is more likely. The matrix material is slightly calcareous.

1.2 - 1.4 m  3A1  2nd buried dark coloured topsoil horizon which is formed on an 8° sloping surface, suggesting the material may be colluvium. The gritty light clay matrix contains a mixture of rounded and more angular lithic fragments (2-50 mm) supporting the notion the material is colluvium. Material is non-calcareous.

1.4 - 2.6 m  3BCk  Highly calcareous, finely bedded (50-100 mm thick), silty clay alluvium. Material is interpreted as fine textured over-bank deposits.

2.6 – 3.5 m  3Ck  Water-worn, clast-supported gravel inter-bedded with sands suggesting the materials are channel type alluvial deposits. Charcoal sampled near base provided a calibrated radiocarbon date of 3,100 ± 350 cal yr BP (Wk9908).

3.5 – 5.8 m  R  In situ Plio-Pleistocene gravels, distinguished by their coarser nature and the presence of highly weathered clasts (Table 6.7).
### Table 6.4 Basic field morphological data for soil site C4

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Horiz</th>
<th>Field Description</th>
<th>Field Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Soil Structure</th>
<th>React HCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.1</td>
<td>1A1</td>
<td>Modern topsoil</td>
<td>CL+</td>
<td>10YR 3</td>
<td>10YR 4</td>
<td>1 SB 2-5mm</td>
<td>0</td>
</tr>
<tr>
<td>0.1-0.6</td>
<td>1B2</td>
<td>Modern B horizon</td>
<td>LC</td>
<td>10YR 3</td>
<td>10YR 5</td>
<td>2 PO 2-5mm</td>
<td>0</td>
</tr>
<tr>
<td>0.8-1.0</td>
<td>2A1</td>
<td>1st Buried topsoil</td>
<td>ZLC</td>
<td>10YR 3</td>
<td>10YR 4</td>
<td>3 PO 2-5mm</td>
<td>0</td>
</tr>
<tr>
<td>1.0-1.2</td>
<td>2B1</td>
<td>B horizon of 1st buried soil</td>
<td>ZLC</td>
<td>2.5Y 4</td>
<td>2.5Y 5</td>
<td>2 PO 5-10mm</td>
<td>2</td>
</tr>
<tr>
<td>1.2-1.4</td>
<td>3A1</td>
<td>2nd buried soil – stony, 8°</td>
<td>Gt LC</td>
<td>10YR 3</td>
<td>10YR 4</td>
<td>2 PO 2-5mm</td>
<td>0</td>
</tr>
<tr>
<td>1.4-2.6</td>
<td>3Bck</td>
<td>Fine textured alluvium</td>
<td>ZLC</td>
<td>2.5Y 5</td>
<td>2.5Y 6</td>
<td>1 SB 10-20mm</td>
<td>3</td>
</tr>
<tr>
<td>2.6-3.5</td>
<td>3ck</td>
<td>Calcareous fine text. all.</td>
<td>LS</td>
<td>5Y 4</td>
<td>5Y 7</td>
<td>0.5 AB 10-20mm</td>
<td>4</td>
</tr>
<tr>
<td>3.5-6.0</td>
<td>R</td>
<td>Ferrihydrite, Plio-Pleist.</td>
<td>-</td>
<td>7.5YR 5</td>
<td>7.5YR 6</td>
<td>- - -</td>
<td>-</td>
</tr>
</tbody>
</table>

**Basic chemical data**

The field stratigraphy, which is indicated by the prefix on each horizon designation, indicates three incipient soil profiles occur in this section. The two buried soils have moderate or strong structural development. The buried topsoils also exhibit 10YR hues and had no reaction to dilute HCl indicating carbonates have either been leached or were not present in the colluvium from which they were derived. The topsoils and other non-calcareous horizons have a lower pH than the subsoils and calcareous alluvial materials indicating either accumulation of organic matter and associated humic acids or absence of carbonate, resulting in lower soil pH values.

### Table 6.5 Basic chemical data for soil site C4

<table>
<thead>
<tr>
<th>Horiz</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A1</td>
<td>0-0.1</td>
<td>Modern topsoil</td>
<td>4.45</td>
<td>7.2</td>
<td>453</td>
</tr>
<tr>
<td>1B2</td>
<td>0.1-0.6</td>
<td>Modern B horizon</td>
<td>0.88</td>
<td>7.1</td>
<td>126</td>
</tr>
<tr>
<td>2A1</td>
<td>0.8-1.0</td>
<td>1st Buried topsoil</td>
<td>2.19</td>
<td>7.2</td>
<td>97</td>
</tr>
<tr>
<td>2B1</td>
<td>1.0-1.2</td>
<td>B horizon of 1st buried soil</td>
<td>0.58</td>
<td>8.1</td>
<td>210</td>
</tr>
<tr>
<td>3A1</td>
<td>1.2-1.4</td>
<td>2nd buried soil – stony, on 8° slope</td>
<td>0.83</td>
<td>7.9</td>
<td>144</td>
</tr>
<tr>
<td>3Bck</td>
<td>1.4-2.6</td>
<td>Fine textured alluvium</td>
<td>0.68</td>
<td>8.1</td>
<td>160</td>
</tr>
<tr>
<td>3ck</td>
<td>2.6-3.5m</td>
<td>Calcareous fine text alluvium &amp; gravel lenses</td>
<td>0.59</td>
<td>7.9</td>
<td>192</td>
</tr>
</tbody>
</table>

The chemical analysis of the horizons (Table 6.5) shows the topsoil layers identified in the field have slightly higher organic carbon levels than the horizons immediately below, supporting their field identification as topsoils. The modern topsoil is particularly high in organic carbon while the buried soils have moderate or low amounts. The electrical conductivity values are low throughout the section with the exception of the surface soil. This material smelt of goat and sheep urine in the field.
Plate 6.5 C4 is an alluvial section with two buried soils in the upper part of the section. Charcoal taken at 0.9m from the surface was dated at $2,090 \pm 140$ cal yrs BP (WK9815 calibrated) and charcoal from the base of the alluvium was dated at $3,100 \pm 350$ cal yrs BP (WK9908). Sample sites are indicated by arrows.

Figure 6.3 Location of site C4 and C8 alluvial sections in the lower catchment (contour interval 20 m). Thick blue line is catchment boundary, light blue line is streams, pink lines are roads.
Atmospheric data from Stuiver et al. (1998); OxCal v3.8 Bronk Ramsey (2002); cub r:4 sd:12 prob usp

**Figure 6.4** Radiocarbon calibration curves for site C4a-b after Stuiver *et al* (1998) using the software of Bronk Ramsey (2002).
1A1 0-0.1 m
Modern topsoil, weak pedality, many 1-15 mm sub-rounded to sub-angular lithic fragments (chert, fine sandstone, ultamafics, non-calcareous colluvium

1B2 0.1 – 0.6 m
Moderate angular pedality, common, rounded to angular lithic fragments (1-20 mm) in fine matrix (ultamafics, fine sandstone, chert, calcrete), non-calcareous, colluvial material

1C 0.6-0.8 m not sampled

2A1 0.8-1.0 m
Strong angular pedality, few 2-10 mm rounded to sub-angular lithic fragments in fine matrix (ultamafics, fine sandstone, chert), non-calcareous, colluvial material

2B1 1.0 – 1.2 m
Moderate angular pedality, subsoil horizon with few rounded lithic fragments of 1-20 mm dia. Slightly calcareous.

Plate 6.6 Micrographs of C4 soil materials (scale in mm)
3A1 1.2 – 1.4 m
Buried topsoil with common angular to sub-rounded lithic fragments 1-20 mm indicating material is colluvial, non-calcareous

3BCK 1.4 – 2.6 m
Highly calcareous fine textured sediment, fine bedding evident in section – material appears to be fine textured alluvium

3CK 2.6 – 3.5 m
Highly calcareous fine textured with some rounded gravel layers and sandy lenses, alluvial material, charcoal sampled

Sample of highly weathered ultra-mafic clasts from the Plio-Pleistocene gravels

Plate 6.6 Continued - micrographs of C4 soil materials (scale in mm)
and perhaps they are the source of the soil salts. The soil pH tends to be higher in the more calcareous layers (3BCk and 3Ck) while the topsoil layers have lower soil pH.

**XRF and XRD analysis of samples**

The XRF analysis highlights the low level of calcium oxide in the upper colluvial part of the section. This is probably due to the different origin of the upper and lower materials. The lower section, consisting of alluvial sediment, is derived from the mid and upper catchments which have more calcareous sediment than the gravelly leached colluvium derived from the Plio-Pleistocene gravels exposed on the slopes of the lower catchment. The two buried soils show calcium carbonate leaching down their respective profiles as the calcium oxide and “loss” levels increase from topsoils to the B and C horizons. Silica, aluminium and iron levels also appear to be much higher in the colluvial materials than in the alluvial materials (3BCk, 3Ck). However this is in part a relative distortion of the values (Si, Al) due to very high calcium oxide levels in the 3BCk and 3Ck.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (m)</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>MgO</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A1</td>
<td>0-0.1</td>
<td>54.91</td>
<td>0.56</td>
<td>10.91</td>
<td>7.15</td>
<td>0.16</td>
<td>5.76</td>
<td>3.68</td>
<td>1.38</td>
<td>1.20</td>
<td>0.14</td>
<td>13.80</td>
<td>99.65</td>
</tr>
<tr>
<td>1B2</td>
<td>0.1-0.6</td>
<td>60.10</td>
<td>0.60</td>
<td>11.68</td>
<td>8.19</td>
<td>0.15</td>
<td>7.05</td>
<td>2.28</td>
<td>1.39</td>
<td>1.32</td>
<td>0.08</td>
<td>7.11</td>
<td>99.95</td>
</tr>
<tr>
<td>2A1</td>
<td>0.8–1.0</td>
<td>58.67</td>
<td>0.60</td>
<td>11.48</td>
<td>8.32</td>
<td>0.19</td>
<td>7.96</td>
<td>1.79</td>
<td>1.18</td>
<td>1.52</td>
<td>0.07</td>
<td>8.27</td>
<td>100.05</td>
</tr>
<tr>
<td>2B1</td>
<td>1.0–1.2</td>
<td>52.05</td>
<td>0.55</td>
<td>10.53</td>
<td>7.15</td>
<td>0.12</td>
<td>7.66</td>
<td>7.32</td>
<td>1.21</td>
<td>1.65</td>
<td>0.10</td>
<td>11.71</td>
<td>100.05</td>
</tr>
<tr>
<td>3A1</td>
<td>1.2–1.4</td>
<td>59.42</td>
<td>0.62</td>
<td>12.02</td>
<td>8.77</td>
<td>0.19</td>
<td>6.34</td>
<td>2.87</td>
<td>1.37</td>
<td>1.20</td>
<td>0.06</td>
<td>7.11</td>
<td>99.97</td>
</tr>
<tr>
<td>3BCk</td>
<td>1.4–2.6</td>
<td>43.92</td>
<td>0.41</td>
<td>7.86</td>
<td>5.84</td>
<td>0.10</td>
<td>7.93</td>
<td>14.63</td>
<td>0.90</td>
<td>1.27</td>
<td>0.09</td>
<td>16.83</td>
<td>99.78</td>
</tr>
<tr>
<td>3Ck</td>
<td>2.6-3.5</td>
<td>40.38</td>
<td>0.36</td>
<td>6.50</td>
<td>4.77</td>
<td>0.08</td>
<td>7.87</td>
<td>18.12</td>
<td>0.85</td>
<td>1.03</td>
<td>0.09</td>
<td>19.65</td>
<td>99.70</td>
</tr>
</tbody>
</table>

Smectite is the dominant mineral in this section with the two buried soils having the highest levels of smectite (35-50%). Quartz is the second most abundant mineral, and is particularly high in the upper modern soil profile. The modern soil contains much higher levels of quartz than the remainder of the section, supporting the idea it is a coarser textured colluvial unit derived from adjacent (somewhat eroded) hill slopes. Plagioclase is the third most abundant mineral in the modern profile, and it appears to be higher in the topsoils than the subsoils of each of the soils. This probably reflects the lighter texture of the modern topsoil and also greater weathering of the topsoils compared to the subsoils.
Table 6.7 Whole soil X-ray diffraction data for site C4

<table>
<thead>
<tr>
<th>Horiz</th>
<th>Depth</th>
<th>5-50%</th>
<th>25%-35%</th>
<th>15-25%</th>
<th>10%-15%</th>
<th>5%-10%</th>
<th>&lt;2%</th>
<th>Calcite</th>
<th>Mica</th>
<th>Amphibole</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A1</td>
<td>0-0.1</td>
<td>Qtz, Smec</td>
<td>Plag</td>
<td>Serp</td>
<td>Chl, K-Feld, Amph</td>
<td>Serp, Mica, K-Feld, Chl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1B2</td>
<td>0.1-0.6</td>
<td>Smec, Qtz</td>
<td>Plag</td>
<td>Serp, Mica, Chlorite</td>
<td>K-Feldspar, K-Feld, Epidote</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2A1</td>
<td>0.8–1.0</td>
<td>Qtz</td>
<td>Plag</td>
<td>Serp, Mica, Chlorite</td>
<td>Amph, Talc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2B1</td>
<td>1.0–1.2</td>
<td>Smec</td>
<td>Qtz</td>
<td>Serp, Mica, Chlorite</td>
<td>K-Feldspar, K-Feld, Epidote</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3A1</td>
<td>1.2–1.4</td>
<td>Qtz Plag</td>
<td>Serp, Chlorite, Mica</td>
<td>Amph, K-Feld</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3BCK</td>
<td>1.4–2.6</td>
<td>Smec Cal, Qtz</td>
<td>Serp, Plag, Mica, Chl</td>
<td>K-Feld, K-Feld</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3Ck</td>
<td>2.6-3.5</td>
<td>Smec Calcite, Qtz Plag</td>
<td>Serp, Mica, Chlorite</td>
<td>Dolo, K-Feld</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>FeO</td>
<td>Goeth</td>
<td>Smec, Serp</td>
<td>Talc</td>
<td>Amphibole</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calcite (calcium carbonate) is very low or absent in the upper metre of the section but then appears at low levels in the subsoil on the 1st buried soil (2B1). Calcite is abundant in the lower profile, i.e., in the alluvial materials. Serpentinite is also moderately abundant throughout the profile, a reflection of the abundance of this mineral in the regional geological materials. Leaching of dolomite may have occurred from both the buried topsoil layers as its abundance increases in both the subsoils. Interestingly no dolomite occurs in the lower pH horizons such as the modern soil profile and the 2A1 horizon. Leaching of carbonates from horizons lowers the pH of most soil materials (Birkeland 1999).

**Chronology**

Samples of charcoal taken from near the top of the section at 90 cm gave a radiocarbon date of 2,010 ± 140 cal yr BP (see Figure 6.4, Wk9815) which indicates that alluvial deposition was completed by the Early Roman period. There is a 95% probability the sample lies between 200BC and 80AD (Stuiver et al. 1998). This indicates the colluvium relates to the Roman period. Charcoal from the alluvium at the base of the section provided a calibrated radiocarbon age of 3,100 ± 350 cal yr BP (Figure 6.4, Wk 9908). There is a 95% probability the sample lies between 1500 BC and 800 BC and a 68% probability it lies between 1380 – 970 BC (Stuiver et al. 1998). This suggests the alluvial aggradation began in the very Late Bronze Age (1600-1100 BC) to Early Iron Age period (1100-750 BC). The Iron Age was a very important period in the region with over 40 sites identified (see Figure 2.2 – 2.5).
Discussion and interpretation

The section consists of a colluvial modern soil capping a buried soil from which charcoal has been extracted and has given a date of 2,010 ± 140 cal yrs BP. This indicates erosion of soil on the hill slopes above the site occurred after about 2.0 cal kyr BP and that alluvial aggradation dominated up until about this time. This uppermost buried soil has a very dark chroma that may in part be a result of burning, as much fine charcoal occurs in the horizon. This soil was subsequently buried by hill slope material. A second buried soil with stone-line forms above fine-textured alluvium at 1.2 m. The base of the section is composed of sandier alluvium and then very gravelly alluvium. The base of this alluvium has been dated at 3,100 ± 350 cal yr BP (WK 9908) which indicates alluvial aggradation began at this site some time in the Late Bronze Age or early Iron Age. This alluvium abruptly overlies in situ Plio-Pleistocene gravels. The section indicates 2.6 m of aggradation in ca 1100 years which provides a sedimentation rate of 2.4 mm/yr. This moderately rapid aggradation is associated with one of the more populus periods in Grevena pre-history as it was in the Late Bronze Age and the Iron Age that Grevena saw a big increase in population with 19 Late Bronze and 41 Iron Age sites being identified. Eight of the Iron Age sites are in the Leipsokouki valley (Wilkie and Savina 1992; Wilkie 1995). Thus the Iron Age may have represented an increase in grazing pressure in the valley leading to greater sediment supply and alluvial aggradation.

The depositional sequence of events at the site is:- IN-CD-OB-COSO-OB-COSO-SL-COSO.

Likely sequence of events

1. Incision of the stream into Plio-Pleistocene gravels prior to 3.1 cal kyr BP.
2. Gullying to provide gravelly material plus some re-working of the Plio-Pleistocene to form gravelly channel deposits.
3. Soil erosion and slope wash higher in catchment to provide fine-textured alluvium.
5. Further fine-textured alluvial aggradation or fine slope wash.
6. A soil develops in mixed alluvium and colluvium.
7. Soil creep leads to modern soil formation.
8. Late or post Roman incision by stream to modern level.

**Site C14 Sirini alluvium**

*Introduction and location*

The site is located in the mid catchment area at latitude 40.1211º N and longitude 21.3860º E (see Figures 6.7 – 6.6). The modern soil on the alluvium was first described as soil P30 by Doyle (1990). The section occurs in a stream bank cutting which exposes 5.2 m of alluvial sediment and a distinct buried soil profile. Recent stream undercutting at the base of the stream bank section has provided exposure of the lower sediments and a charcoal bearing horizon. Samples of the soil materials and charcoal were taken for analysis and radiocarbon dating for the present study.

The stratigraphy outlined below shows the full sequence of materials. The depth and thickness of the buried soils, colluvial and alluvial materials varies along the length of the section as shown in Plates 6.7 and 6.8. The section appears to be composed of two alluvial component units separated by a moderately developed alluvial soil and on the left side of the section some soil-like colluvium. Plate 6.9 shows images of the soil materials and Tables 6.8 and 6.9 provide physical and chemical details.

*Field Stratigraphy and microscopy*

<table>
<thead>
<tr>
<th>Depth</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.2 m</td>
<td>1A1</td>
<td>Thin modern soil profile with moderately developed soil structure in the topsoil otherwise incipient development and slightly calcareous (see Appendix 2, P30 for more details of modern soil).</td>
</tr>
<tr>
<td>0.2 – 1.4 m</td>
<td>1C1</td>
<td>Fine-textured (fine sandy and silty), bedded alluvium, typical of overbank type deposits.</td>
</tr>
<tr>
<td>1.8 – 2.0 m</td>
<td>1C2</td>
<td>Fine gravel, rounded, clast supported, typical of alluvial channel deposits.</td>
</tr>
<tr>
<td>2.0 – 3.0 m</td>
<td>1C3</td>
<td>Fine layering (5 – 20 cm), generally fine textured silts and fine sands with occasional gravel stringer, sediment typical of stream over-bank deposits</td>
</tr>
</tbody>
</table>
3.0 – 3.3 m  2A1  Dark coloured, strongly structured layer with 7.5YR 4/6 ferruginous coatings on peds (mottles), interpreted as a thin soil profile, thickness varies along section.

3.3 – 3.5 m  2B2  Incipient B horizon of topsoil described above, highly calcareous – soft carbonate lining tubular pores, moderate pedality

3.5 – 4.4 m  2C  Clast-supported, water-worn gravels of sandstone, bedded, well sorted indicating material is channel type stream deposits. Basal contact in places appears erosional as channels are cut into finer sediment below.

4.4 – 5.2 m  4C  Fine-textured alluvium containing large pieces of charcoal provided a date of 4,150 ± 500 cal yrs BP.

On left part of section (refer to plate 6.8)

2.1 – 2.6 m  3AB  Lying beneath the buried soil described above (at 3.0 – 3.5 m) is a material with silty clay loam texture, moderate soil structure, sub-angular gravel fragments “floating” in the matrix all indicating the deposit is soil is pedogenic colluvium. The shape and orientation of the deposit suggests the colluvium comes from the slopes to the south of the site.

Charcoal was sampled at 5 m below the terrace surface (4C layer) and indicates the main alluvial aggradation began after about 4.15 ± 0.5 cal kyr BP, i.e., in the Middle Bronze Age. The charcoal occurs in fine-textured alluvium and this is capped by coarse channel-type gravel deposits and then further fine-textured alluvium in which distinct, thick topsoil has developed. The charcoal has been transported down stream and thus provides a maximum date.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Hor Description</th>
<th>Field Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev</th>
<th>Ty Size</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.2</td>
<td>1A1  Modern topsoil</td>
<td>ZCL-</td>
<td>2.5Y 4 2</td>
<td>2.5Y 5 2</td>
<td>2 SB 5-10mm</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3.0-3.3</td>
<td>2A1  1st buried soil - at deeper part</td>
<td>ZLC-</td>
<td>2.5Y 4 2</td>
<td>2.5Y 5 2</td>
<td>3 PO 10-20mm</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3.3-3.5</td>
<td>2B1  1st buried soil – subsoil</td>
<td>ZCL+</td>
<td>2.5Y 4 2</td>
<td>2.5Y 7 2</td>
<td>2 PO 10-50mm</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2.1-2.6</td>
<td>3A1  Soil-like colluvium (along sect)</td>
<td>ZCL</td>
<td>2.5Y 4 3</td>
<td>2.5Y 6 3</td>
<td>2 PO 20-50mm</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4.8-5.0</td>
<td>4C  Charcoal in sandy alluvium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Plate 6.7 Site C14 Sirini alluvium, note buried alluvial soil in lower part of section lying above gravelly channel deposits. Charcoal taken from base of section in over-bank deposits - marked by mattock handle gave age of $4,150 \pm 500$ years BP (WK9919, calibrated). Well-fired, wheel-made pottery and a bovine tooth (male) found at 2 m from surface (tape = 2 m). Section indicates gravelly channel deposits began to accumulate after Early - Middle Bronze Age this is followed by accumulation of over bank deposits which in the later 0.5 m were slow enough so as to allow soil development.

Plate 6.8 Site C14 photographed in 1988 10 m to left of photo above. Note the Bronze Age soil rises to the right and then separates into two soil layers to the right of the bush. Also note the thicker channel deposits above the buried soil in left of photograph.
Figure 6.5 Radiocarbon calibration curves for sites C14, C3, and P52 after Stuiver et al (1998) using the software of Bronk Ramsey (2002).
1A1 0 – 0.2 m
Modern topsoil, moderate sub-angular pedality (A & B). Slightly calcareous, few fine (1-2 mm) sub-rounded coarse fragments (C)

2A1 3.0 - 3.3 m
Buried topsoil, 1st buried soil, strong angular pedality, ferruginous coatings lining root channels (C & D – see Figure 6.6), very slightly calcareous, due to fine deposits on few ped surfaces (B)

2B1 3.3 - 3.5 m

3AB 2.1- 2.6 m
Soil-like colluvium, sub-angular and sub-rounded fragments of sandstone (C) indicate material may be colluvial in origin, highly calcareous, carbonate in veins and pores (B), also fine (<5 mm) snail shells

Plate 6.9 Micrographs of C14 soil materials (scale in mm)
Figure 6.6  ESEM spectral analysis from ferriferous coating on soil aggregate from buried alluvial soil at C14 (2A1 at 3.0-3.3 m). The spectra shows a strong iron signal confirming the ferruginous nature of the coating. Silica, magnesium, aluminum, calcium and oxygen are also high suggesting the typical range of minerals, namely quartz and smectite with lesser mica.

Plate 6.10  ESEM micrographs of the surface of a ferruginous coating on soil aggregates in the buried 2A1 horizon (3.0 - 3.3 m) of site C14. See also see Plate 6.8. ESEM spectra analysis confirms this by showing a strong iron signal (see figure below).
Figure 6.7 Location of sites C2, C14 and C17 (contour intervals are 4 m and grid 500 m)

Figure 6.8 Location of sites in central study area (contour intervals are 20 m). Thicker blue line is catchment boundary, thin blue line is the stream, thin pink lines are roads, villages and cultural features marked in pink.
Basic chemical data

The buried soil at 3.0 – 3.5 m shows carbonate has been leached from the topsoil into the subsoil. Plate 6.9 shows the carbonate lining tubular pores in the 2B1. This soil also expresses strong structural development and the formation of distinct ferruginous coatings (mottles) on root channels (see Plates 6.9 and 6.10). An ESEM micrograph of a ferruginous coating indicates a very strong iron peak in addition to Si, Mg, Al and O peaks typical of quartz and 2:1 clay minerals. Plates 6.7 - 6.9 and Table 6.8 show the moist topsoil colours are dark although the hue is on the yellow end of the spectrum (2.5Y). Textures of the soil horizons are typically silty clay loams and this suggests the alluvial soils are dominantly formed in fine overbank or slope wash deposits.

Data presented in Table 6.9 indicate alkaline soil pH values in the modern topsoil and the buried soils. The modern and buried topsoils also have higher organic carbon levels than other materials i.e., buried B horizons and soil-like colluvium. There is some indication of leaching of carbonate in the 1st buried soil. Leaching of the buried topsoil is indicated by the increase in pH with depth.

Table 6.9 Basic chemical data for soil site C14

<table>
<thead>
<tr>
<th>Hor</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon</th>
<th>pH 1:5 soil:water</th>
<th>EC μS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A1</td>
<td>0-0.2</td>
<td>Modern topsoil</td>
<td>1.69</td>
<td>8.0</td>
<td>262</td>
</tr>
<tr>
<td>2A1</td>
<td>3.0-3.3</td>
<td>1st buried soil - at deeper part of section</td>
<td>1.26</td>
<td>8.0</td>
<td>279</td>
</tr>
<tr>
<td>2B1</td>
<td>3.3-3.5</td>
<td>1st buried soil – subsoil</td>
<td>0.62</td>
<td>8.4</td>
<td>164</td>
</tr>
<tr>
<td>3A1</td>
<td>2.1-2.6</td>
<td>2nd faint buried soil-like colluvium (along section)</td>
<td>0.37</td>
<td>8.3</td>
<td>285</td>
</tr>
<tr>
<td>4C</td>
<td>4.8-5.0</td>
<td>Charcoal 0.2-0.5 m from base</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chronology

Charcoal taken from the base of the alluvium provides a radiocarbon date of $4,150 \pm 500$ cal yr BP (calibrated Wk 9919) and suggests alluvial aggradation began after the Early Bronze Age. This was associated with gully erosion as gravelly alluvium is deposited along with sandier alluvium. The alluvial deposition was followed by colluvial activity and partial burial of the site by soil-like colluvium. A pause in the rate of both alluvial and colluvial deposition allowed a soil to develop on the sediment. The soil has distinct mottling, and a deep dark topsoil, in the lower part of the section (left side) suggesting seasonal surface waterlogging on the lower lying
parts of the valley (see 2A1 in Plate 6.9). Soil development was halted by rapid alluvial deposition at the site. This appears to have accumulated during the classical and Hellenistic periods as indicated by well-fired wheel-made pottery observed but not sampled from the gravelly part of the upper section (see Plate 6.7). A bovine tooth fossil was also noted in this gravel layer at 1.8 – 2 m from the modern soil surface (Rassios 2003). This section suggests the Sirini alluvium was deposited in at least two distinct events, an aggressive alluvial and colluvial sedimentation post Middle Bronze Age followed by soil formation (ca 500 years) – Sirini A. This was followed by a later phase of alluvial deposition composed initially of channel deposits and then over-bank deposits – Sirini B. This is likely to have occurred in the Classical to early Roman periods based on the historic pot sherds in the upper 2 m of the section (Wilkie and Savina 1992).

The depositional sequence is:- IN-OB-IN-CD-OB-CO-SO-CD-OB-SO.

Discussion and interpretation
The sequence began with valley incision to the level of bedrock prior to 4.15 cal kyr BP. This was followed by alluvial sedimentation of fine textured alluvial materials containing abundant coarse charcoal, indicating fires in the catchment and providing a date of 4.15 cal kyr BP. The charcoal was very coarse (pieces 3 -10 mm) and thus may represent trees of moderate age ~ 500 years. This may mean aggradation did not begin until the late Bronze Age to Iron Age period. This is when gravelly channel then over-bank deposits and colluvium were laid down. A soil then developed on the sediments, having a mottled profile in the lower landscape positions. When the soil formed is not known, but it is covered by alluvium with historic pot sherds and so is likely to be during the Archaic to early Classical periods of occupation. This period would offer the most stable conditions for soil formation post 4.15 cal kyr BP. The soil was rapidly buried by gravelly and then fine alluvium. Sometime following the alluvial aggradation the stream has re-incised to the bedrock. A weak A/C soil profile has developed on the terrace surface.

The one radiocarbon date at the site makes estimation of sedimentation rates difficult. However the historic sherds and knowledge from other sites helps a little. If the base of the section is taken as 4.15 cal kyr BP and the top as ca. 2 cal kyr BP as indicated at site C4 then a sedimentation rate of 2.4 mm/yr is determined. A number that is
close to the sedimentation rate of 2.7 mm/yr determined for the Syndendron alluvium at P37.

**Site C3 Sirini alluvium**

*Introduction and location*

The site is located in the mid catchment area at latitude 40.12040° N and longitude 21.39470° E (see Figures 6.8 and 6.10 and Plates 6.11 - 6.12). The site was described in the field and a sample of charcoal was taken for radiocarbon dating at 1.8 m above the base of the section. The entire section was not accessible for sampling and thus only charcoal was collected in the field (see Plates 6.11 - 6.12). A vertebra of a sheep or goat was noted in river gravels at 2.5 - 3m above base of the section. Water-worn but well-fired pottery occurs in the gravels of the lower section. Fine textured sediment with a distinct gleyed soil profile form at the base of the section. Three dark traces reminiscent of buried soils or soil-like colluvia could be seen in the mid and upper parts of the section (see Plate 6.11). These could not be reached without climbing ropes.

*Field Stratigraphy*

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.4 m</td>
<td>Modern soil with shallow profile.</td>
</tr>
<tr>
<td>0.4 - 5 m</td>
<td>Fine sand and silty bedded sediment, typical of overbank deposits. Three faint topsoil horizons within the stratified alluvium (sands with some and grit layers). In the left-hand part of section faint and discontinuous soil horizons occur at approximately 0.5 m, 2.0-2.5 m and 4-4.5 m from the terrace surface. This unit indicates overbank type conditions with weak topsoils forming during periods of slower alluvial accumulation.</td>
</tr>
<tr>
<td>5 – 6.5 m</td>
<td>Water-worn, moderately well sorted, well rounded, gravels and stones forming alluvium in lenses and beds up to 1.2m thick. Probably channel deposits of braided alluvial fan. Sheep/goat vertebrae in the gravels at 2.5-3 m from base of section (see Plate 6.12). Charcoal was collected at 1.8 m from base of section and dated to 3,025 ± 325 cal yr BP (see Figure 6.5, Wk9814).</td>
</tr>
<tr>
<td>6.5 – 7.8 m</td>
<td>A weakly expressed soil profile is developed in fine textured overbank deposits at the base of the section. The topsoil is weakly expressed</td>
</tr>
</tbody>
</table>
with 2.5Y 4/2 Munsell colour and weak soil structure and the silty clay loam subsoil is gleyed with bluish grey colour with orange mottling.

Chronology
Charcoal was taken at 1.8 m from the base of the section, above the lower gleyed soil profile and provided a date of $3,025 \pm 325$ cal yr BP (see Figure 6.5). This date near the base of the sedimentary section indicates significant alluvial deposition starting in the Late Bronze to Early Iron Age. The sediment is gravelly initially indicating gully erosion was probably a factor in local side-valleys, which are likely to be the primary source of sediment.

Discussion and interpretation
The site represents nearly 8 m of alluvial sediment deposited in the late Holocene. The sequence must have started with the stream incising down to bedrock followed by the deposition of 1.3 m of fine-textured alluvial material. A weakly developed gley soil developed on this material prior to $3.0 \pm 0.3$ cal kyr BP suggesting the site was waterlogged at this time. This soil was then buried by gravelly alluvium after about 3.0 cal kyr BP. The gravelly alluvium contains water-worn pot sherds as well as a goat/sheep vertebrae indicating human activity in the catchment at the time (Plate 6.12). The coarse gravelly alluvium indicated gully incision may have begun at this time in the side valleys. The gravels are then capped by finer alluvial sediment with a few faint topsoil horizons developing. These are taken to represent brief stable periods during which organic matter could accumulate in the sedimentary materials. These fine sediments are taken to indicate overbank type stream deposits; they are approximately 4 – 5 m thick.

The interpretation at this site is that a small amount of alluvial deposition (1.4 m) was followed by soil formation and gleying, probably due to a low lying landscape position. This occurred prior to 3.0 cal kyr BP. This was followed by aggressive aggradation with gravel deposits and inter-bedded finer sediment totalling about 3 m in thickness. The gravels in some parts of the section have the form of paleo-channels indicating the gravels represent aggressive channelised flow regimes. The incision of the valley and gullying in side-streams would provide a ready source of coarse material for the gravelly and stony basal deposits. Alluviation would have continued.
Plate 6.11  Site C3 Sirini alluvium with charcoal taken 1.8 m from base dated at 2,785 $\pm$ 128 years BP (Wk9814, calibrated to 3,025 $\pm$ 325). Charcoal taken at level of mattock handle as shown in right-hand plate below. A bluish grey, gleyed soil occurs at base of section. Note gravelly channel deposits in mid section and finer alluvium above. Sheep/goat vertebrae found in gravels above assistant’s white hat.
Plate 6.12 Site C3 A above shows a close-up view of a buried alluvial soil with bluish grey, gleyed subsoil (below authors hand at base of section). Radiocarbon-dated charcoal comes from the alluvial gravels at the level of the mattock handle. The date is 3,025±325 BP (calibrated Wk9814) i.e., Late Bronze Age-Early Iron Age. Plate B below shows sheep or goat vertebrae (Friend 2003) and carbonate cemented fragment found at 2.5-3 m from base of section on which the author is standing.
as long as adjacent gullies incised and generated coarse material. As the gullies subsided finer sediment from gully sides and colluvium from surrounding slopes was transported resulting in finer sedimentation, with some brief periods of topsoil formation. Sedimentation continued until a depth of approximately 8 m of sediment had accumulated. At some later stage the valley re-incised the alluvium to the present level, probably post 2.0 cal kyr BP as suggested by site C4.

Some of the channel deposits in the lower part of the section are laid down at angles of up to 14-16° supporting the notion these deposits are alluvial fan materials derived from nearby gullies. Several major side-streams occur upstream that could have acted as a sediment source.

There are similarities between this site and C14. Both sites have a thin layer of fine-textured alluvium at the base of the section; at this site the material is gleyed. At both sites this material is capped by coarse gravelly alluvium and overbank deposits. At this site the gravelly alluvium is Early Iron Age or younger while at C14 the gravelly alluvium is only known to be younger than 4.15 cal kyr BP.

An estimation of the sedimentation rate at this site can only be made if the cessation of deposition is taken as that at C4 i.e., 2.0 cal kyr BP. This gives a very high sedimentation rate of 7.6 mm/yr. Even if the sedimentation continued until 1.0 cal kyr yr BP the rate would still be approximately 4 mm/yr. Thus no matter which way it is viewed this site indicates very high sedimentation rates post 3 cal kyr BP.

The depositional sequence at the site is:- IN-OB-SO-CD-OB-SO-OB-SO-OB-SO-OB-SO-OB-SO-OB-SO.

**Site C16 Sirini alluvium capped by colluvium**

*Introduction and location*

The site is located near Paleokastro in the mid catchment area latitude 40.13140° N and longitude 21.36390° E. The site shows an alluvial section capped by colluvium and rests in a gullied valley adjacent to site C9 (see Plate 6.13 and Figure 5.5). The alluvium is composed of fine gravels and grit derived from mudstone. The section is approximately 10 m thick. The colluvial soil that caps the alluvium contains well
fired, wheel-made pot sherds, including loom weights (Plate 6.13). This soil has been radiocarbon dated and it is capped by gritty alluvium/slope wash and further soil-like colluvium that has also been dated.

**Field stratigraphy and microscopy**

0-1.6 m  1AB  Bedded, pale grey, silty clay loam with some large angular stones (20 – 100 mm) and common sub angular lithic fragments (2 – 20 mm) indicating the material is formed from colluvial deposits, probably with bedrock exposed upslope producing the stone sized fragments.

1.6–1.9 m  2A1  Dark coloured silty clay loam with strong structure indicating a topsoil horizon, contains much charcoal, sampled and radiocarbon dated to 1,735 ± 135 cal yr BP (see Figure 6.9, Wk9921).

1.9 – 3.3 m  2C  Bedded (3-6 cm thick) grit sized sediment derived from mudstone, fragments are dominantly sub-angular and well sorted in fine layers indicating the material is alluvial.

3.3 – 3.6 m  3A1  Dark, structured topsoil layer containing many angular, well fired, wheel made pot sherds with vase rims and loom weights (Plate 6.13). Charcoal sampled from profile provided a radiocarbon date of 2,295 ± 145 cal yr BP (see Figure 6.9, Wk9922).

3.6 – 10 m  3C  Bedded grit to fine gravels, sub-rounded to sub-angular shape, in beds 20-30 cm thick, interpreted as alluvial sediment. Shape of fragments reflects the very short distance of travel, i.e. from up local gully.

At 10 m  R  Bedrock base of stream.

### Table 6.10  Basic field morphological data for soil site C16

<table>
<thead>
<tr>
<th>Hor</th>
<th>Depth (m)</th>
<th>Description</th>
<th>Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev.</th>
<th>Ty</th>
<th>Size</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>1AB</td>
<td>0-1.6</td>
<td>Colluvial (at 0.75 m)</td>
<td>ZCL</td>
<td>2.5Y</td>
<td>4 2</td>
<td>2.5Y 6</td>
<td>3</td>
<td>PO</td>
<td>5-10 mm</td>
</tr>
<tr>
<td>2A1</td>
<td>1.6-1.9</td>
<td>1st buried soil Colluvial/alluvial or slope wash between 2 soils sample at 2.4 m</td>
<td>ZCL+</td>
<td>2.5Y</td>
<td>3 3</td>
<td>2.5Y 5 2</td>
<td>3</td>
<td>PO</td>
<td>2-20 mm</td>
</tr>
<tr>
<td>2C</td>
<td>1.9-3.3</td>
<td>2nd buried soil Colluvial/slopeswash materials</td>
<td>ZCL</td>
<td>5Y</td>
<td>5 3</td>
<td>5Y 7 2</td>
<td>0</td>
<td>SG</td>
<td>0</td>
</tr>
<tr>
<td>3A1</td>
<td>3.3-3.6</td>
<td>Alluvial slope wash materials</td>
<td>ZLC-</td>
<td>2.5Y</td>
<td>3 2</td>
<td>2.5Y 2</td>
<td>2.5</td>
<td>PO</td>
<td>5-20 mm</td>
</tr>
<tr>
<td>3C</td>
<td>3.6-10 at 4.3</td>
<td>Alluvial slope wash</td>
<td>ZCL</td>
<td>5Y</td>
<td>4 3</td>
<td>5Y 6 2</td>
<td>0</td>
<td>SG</td>
<td>10-20 mm</td>
</tr>
<tr>
<td>3C</td>
<td>At 7</td>
<td>Alluvial slope wash</td>
<td>ZCL</td>
<td>5Y</td>
<td>4 2</td>
<td>5Y 6 2</td>
<td>2</td>
<td>PO</td>
<td>0</td>
</tr>
</tbody>
</table>
Plate 6.13 Plate A shows site C16 with layered alluvial sediment occurs below the yellow tape. This is capped by dark colluvial soil (at base of tape), capped by more layered alluvium/slope wash and buried soil (top of tape) – finally the whole section is capped by slope deposits and soil-like colluvium. Plate B below shows pottery and bone fragments found in buried soil at base of tape (see arrow).
Figure 6.9 Radiocarbon calibration curves for site C16a-b after Stuiver et al. (1998) using the software of Bronk Ramsey (2002).
Plate 6.14 Micrographs of C16 soil materials (scale in mm)
Plate 6.14 continued  Micrographs of C16 soil materials (scale in mm)

3A1 3.3-3.6 m
Strongly pedal (A), dark topsoil layer with bone, pot sherd and rock fragments (B, C), slightly calcareous

3C at 4.3 m
Alluvium with sub-rounded shapes and moderately sorted (A - C), calcium carbonate deposited in pores (B), strongly calcareous

C3 at 7 m
Alluvium with 2 – 6 mm sub-angular shape (C) and moderate sorting (A)
Table 6.10 shows the buried topsoils have stronger soil structure, heavier textures, lower reaction to dilute HCl and darker soil colours. These factors all support the notion that the dark, structured layers are in fact topsoils, however they may have been partly derived from soil materials upslope.

Table 6.11 shows the soil pH values are slightly alkaline throughout with the highest pH values in the alluvial slope wash materials 2C and 3C. The two buried topsoils display the highest organic carbon levels, supporting their field identification as such.

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon</th>
<th>pH 1:5 soil:water</th>
<th>EC mS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1AB</td>
<td>0-1.5</td>
<td>Soil-like colluvial unit (sample 0.7m)</td>
<td>0.56</td>
<td>8.1</td>
<td>164</td>
</tr>
<tr>
<td>2A1</td>
<td>1.7-1.9</td>
<td>1st buried soil horizon</td>
<td>1.01</td>
<td>8.1</td>
<td>200</td>
</tr>
<tr>
<td>2C</td>
<td>1.9-3.3</td>
<td>Colluvium between 2 soil materials (sample at 2.4 m)</td>
<td>0.43</td>
<td>8.3</td>
<td>137</td>
</tr>
<tr>
<td>3A1</td>
<td>3.3-3.6</td>
<td>2nd buried soil horizon</td>
<td>1.62</td>
<td>8.2</td>
<td>224</td>
</tr>
<tr>
<td>3C</td>
<td>at 4.3</td>
<td>Alluvial slope wash materials</td>
<td>0.26</td>
<td>8.5</td>
<td>112</td>
</tr>
<tr>
<td>3C</td>
<td>at 7</td>
<td>Alluvial slope wash</td>
<td>0.91</td>
<td>8.0</td>
<td>241</td>
</tr>
</tbody>
</table>

Chronology

Two charcoal samples have provided radiocarbon dates for the buried soil horizons. They indicate significant alluvial deposition (>7 m) in the gully was followed by soil development and accumulation of pot sherds at of 2,295 ± 145 cal yr BP (Wk9922 calibrated at 95.4% confidence). A lot of angular (broken) pot sherds occur in this soil with loom weights, black glaze, rims with sequences of holes and even finger prints on black glaze i.e., Classical – Hellenistic sherds. This soil was then buried by either slope wash or more alluvium before soil formation recommenced at 1,735 ± 135 cal yr BP (Wk9921 calibrated 95.4% confidence).

Discussion and interpretation

Site C16 helps date the commencement of the gullying process in the Leipsokouki catchment as the deposit partly fills a prior gully. The sediment at C16 has been preserved due to its position at the confluence of two gullied valleys. The dated soil on the gully fill sediment indicates the gully must have been cut and then refilled before 2.3 cal kyr BP but after 8.1 cal kyr BP as indicated by the adjacent site C9. The bedded alluvial sediment in the gully contains gritty layers (2 – 6 mm sized
particles) of soft mudstone. These soft, sub rounded fragments reflect a short transport distance and indicate the material is derived from fretting mudstone on the walls of the gully and surrounding slopes. The sedimentation may be interpreted as the change-over period of active gully incision to sediment over-supply and gully filling.

The 2.3 cal kyr BP soil is capped by more alluvium indicating fluvial sedimentation continued after this time. At about 1.7 cal kyr BP a second soil is formed and this is in turn was buried by soil-like colluvium. This date helps indicate the timing of the completion of the Sirini alluvial event. Site C4 in the lower catchment has indicated it may have been soon after 2.0 cal kyr BP, but this site indicates the end of the Roman period is a better estimate. As with several other sites in the valley the cessation of alluvial activity was followed by colluvial deposition over the alluvial deposits as slopes readjusted.

If the initiation of the Sirini B alluvial sedimentation at this site was similar to that at sites C3 and C4 i.e., ca 3.1 cal kyr BP then this gives a sedimentation rate of 6.1 mm/yr for the period 3.1 - 1.7 cal kyr BP. This rate is close to that in the mid catchment site C3 (7.6 mm/yr) but well above the figure for C4 in the lower catchment (2.4 mm/yr). If only the upper part of the section is considered i.e., between 2.3 – 1.7 kyr the rate drops to 2.7 mm/yr. However if the lower part of the section lies between ca 3.1 - 2.3 cal kyr BP this derives a very rapid sedimentation rate of 8.4 mm/yr. This would suggest the most rapid alluvial sedimentation in this part of the catchment occurred during the Iron Age to Hellenistic Periods.

Site C2 - Sirini alluvium in mid catchment

Introduction and location
The site is located at latitude 40.12050° N and longitude 21.38740° E in the mid catchment area and is 120 m downstream of site C14 (Figures 6.7 and 6.10). The section represents 8 m of alluvial sedimentation. Radiocarbon dating was undertaken on charcoal from soil-like colluvium capping the site (Plate 6.15). The site was dated in an attempt to determine the close of the Sirini alluvium. Unfortunately the radiocarbon date returned was very young and only indicates recent colluvial activity.
at the site. Only small parts of the section were visible due to slumping of the
exposure and vegetation.

Several soil and sediment samples were taken for analysis and field descriptions are
presented below and in Tables 6.12 and 6.13.

Field stratigraphy and microscopy

0 – 0.9 m  1A1  Dark greyish brown, silty clay loam with few sub-angular
gravel “floaters” set in soil matrix indicating the soil
materials appear to be of colluvial origin.

0.9 – 1.2 m  2A1  Very dark greyish brown, strongly structured, silty clay loam
with sub-angular “floaters” suggesting sediment is soil-like
colluvium, charcoal sample provided a radiocarbon date of
380 cal yr BP ± 90 (see Figure 6.11, Wk9183).

1.2 – 1.8 m  2C  Fine-textured alluvium with lenses of well sorted, clast
supported rounded and sub rounded gravels. Gravel beds dip
into the valley at 4° – 6° suggesting they form part of a fan.
There are some gravelly lenses in right hand part of the
section but the majority of material appears to be overbank
with lesser channel deposits.

Note: - slumping obscures most of the base of the section.

1.8 – 2.4 m  3A1  On the left-hand side of the exposure a buried soil profile was
exposed in the lower part of the section, this soil-like layer
also has sub-angular “floaters” indicating it may be derived
from colluvial soil materials

Below 2.4 m  3C  Fine-textured, stratified alluvium with coarse, well sorted,
rounded, gravels occurring in lenses interpreted as overbank
and channel deposits.

The depositional sequence is thus IN-CD+OB-SO-CD+OB-SO-CO.
Table 6.12 Basic field morphological data for soil site C2

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Hor</th>
<th>Description</th>
<th>Texture</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev</th>
<th>Ty Size</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.15</td>
<td>1A1</td>
<td>Modern topsoil</td>
<td>ZCL+</td>
<td>2.5Y 4</td>
<td>5Y 6</td>
<td>2 PO 2-5mm</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>0.9-1.2</td>
<td>2A1</td>
<td>1st buried soil</td>
<td>ZCL+</td>
<td>2.5Y 3</td>
<td>2.5Y 5</td>
<td>2 PO 2-5mm</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1.8-2.4</td>
<td>3A1</td>
<td>2nd buried soil</td>
<td>ZLC-</td>
<td>2.5Y 4</td>
<td>2.5Y 6</td>
<td>2 PO 2-5mm</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.11 shows the topsoils all have a dark moist colour and moderate soil structural development. The buried topsoils have a lower reaction to dilute HCl indicating they have either been derived from materials with lower levels of calcium carbonate than the surface soil colluvium. Soil textures are silty clays or silty clay loams and suggest they are derived from soil-like colluvial or fine textured overbank type deposits (3A1). However the sub rounded to sub angular coarse fragments that float in the finer matrix in the upper soils suggest they are of colluvial origin.

Table 6.13 Basic chemical data for soil site C2

<table>
<thead>
<tr>
<th>Hor</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC mS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A1</td>
<td>0-0.15</td>
<td>Modern topsoil</td>
<td>1.44</td>
<td>8.2</td>
<td>270</td>
</tr>
<tr>
<td>2A1</td>
<td>0.9-1.2</td>
<td>1st buried soil</td>
<td>1.37</td>
<td>8.0</td>
<td>237</td>
</tr>
<tr>
<td>3A1</td>
<td>1.8-2.4</td>
<td>2nd buried soil</td>
<td>0.51</td>
<td>8.3</td>
<td>187</td>
</tr>
</tbody>
</table>

The moderate soil organic carbon levels support the notion the 1A1 and 2A1 layers are topsoil horizons. The organic carbon is lower in the 3A1 and this may be due to a very brief period of soil development during the alluvial aggradation. The electrical conductivity values indicate soil salinity is not an issue at the site and the soil pH values are in the alkaline range which is typical of calcareous soil materials.

Chronology

The charcoal taken for dating from this upper part of the section indicates the site was receiving colluvium as recently as 380 cal yrs BP. This site is useful in that it demonstrates the role slope processes have in supplying soil-like materials to alluvial sections lying on the valley floor. The soil materials appear to be derived from soil colluvium from the surrounding slopes that can be seen to be largely denuded of soil cover (see Plate 6.15).
Layered alluvium, deposited on gentle slope indicating it is part of a fan alluvium sourced from gully upstream

Soil colluvium, derived from adjacent slope dated to only $380 \pm 90$

Plate 6.15 Site C2, 30 m downstream of site C14 is also composed of Sirini alluvium. The alluvium is only exposed in small parts of the section due to slumping and vegetation. The alluvium is capped by a soil colluvium which although quite dark returned a very young date of $380 \pm 90$ years BP (Wk9183, calibrated) indicating some colluvia is very young.

Figure 6.10 Location of sites C3 and P52 in mid catchment area. Contours at 4 m intervals and the map grid is at 500 m intervals.

288
1A1 0-0.9 m
Moderate pedal angular pedality (A), worm channels (B) and few sub-rounded lithic fragments (B) matrix moderately calcareous

2A1 0.9 – 1.2 m
Strong pedal dark topsoil layer (A), moderately calcareous with 2-25 mm, rounded to sub-angular, lithic fragments (C) floating in finer matrix – suggests material is colluvial

3A1 1.8-2.4 m
Moderate angular pedality (A), moderately calcareous with soft coatings and veins of carbonate (B), few sub-rounded to sub-angular lithic (D)

Plate 6.16 Micrographs of C2 soil materials (scale in mm)
Discussion and interpretation

The upper soil materials from which the charcoal was sampled appears to be colluvial in nature i.e., it is mixed fine matrix with coarser “floaters”. This material was deposited on an erosional slope cut across gravelly alluvial sediments (Plate 6.15) and the deposit thickens down slope; all these features are typical features of colluvial slope deposits. A fine textured soil-like colluvial deposit occurs in the mid section and it also contains “floaters”. It is underlain by coarse, rounded, clast-supported gravel; interpreted as channel deposits. These are inter-bedded with layers of fine sand and silt that are more typical of overbank deposits. The beds dip into the valley at 40 - 60° indicating the sediment forms part of an alluvial fan.

The depositional sequence at this site involved progressive valley filling with alluvium of both channel and overbank type deposits. One short pause in valley aggradation allowed an incipient soil to develop. Alluvial deposition continued until the surface reached approximately 8 m in height above the modern stream level. Sometime following this, slope processes began to dominate involving firstly erosion of the alluvial materials, providing a truncated sloping section. On this slope two soil-like colluvia were deposited, the first at about 380 cal yr BP (Plate 6.14).

Review of site P52 Sirini alluvium

Soil profile P52 is located in the mid catchment at latitude 40.1178° and longitude 21.4043°, 800 m west of the village of Mega Sirini (Figure 6.8). The modern soil overlies 9.6 m of dominantly alluvial sediment consisting of stratified silts and sands with occasional fine gravel stringers. Two buried soil horizons occur and these appear to be soil-like colluvium (Plate 6.17). This site was described and radiocarbon dated at 2,450 ± 300 cal yr BP (see Figure 6.5, Wk1579) by Doyle (1990) at 6.5 m from the modern soil surface (see site description in Appendix 2).

The radiocarbon date indicates alluvial sedimentation began before 2.45 cal kyr BP, as approximately 3 m of sediment lies below the dated layer. However, the majority of sedimentation occurred in the Classical - Roman Periods. The terrace contains two significant buried soils at 1.5 and 4.4 m from the soil surface (see Plate 6.17 and Appendix 2). Both the buried topsoils appear to be of colluvial origin as they contain
Plate 6.17 Soil profile P52 radiocarbon dated at 6.5 m from surface (photo A) and calibrated to $2,450 \pm 300$ BP (calibrated WK1579). Photo B shows other side of section with buried colluvial soil shown with gravel “floaters” suggesting it is of colluvial origin.
angular and sub-angular coarse fragments floating in the finer silty clay loam matrix. The colluvial origin helps explain the dark colours, strong soil structure and silty clay loam texture in a deposit of relative youth (Doyle 1990).

The largely fine-textured nature of this deposit is at odds with most other Sirini alluvial sections which typically have gravelly deposits toward the base. This may indicate that the gravels associated with the Sirini alluvium are restricted to channels with finer sediment either removed from the catchment or deposited on the aggrading flood plain and levees. Such an interpretation is in agreement with the deposits associated with C3 where gravel deposits can be seen to form channels in the section. An alternative interpretation is that the site represents a distal fan or river terrace setting and hence it formed from finer sediment.

The sedimentation rate can be estimated at the site for the parts of the section above and below the radiocarbon dated level. If the start of the alluvial aggradation is taken to be similar to C3 and C4 then the sedimentation rate of the lower section is 5.9 mm/yr. This is lower than the rate at C16, which was 8.4 mm/yr, during a similar time period, however site C16 was confined in a tributary valley which would allow greater vertical aggradation of a similar volume of sediment. The sedimentation rate in the upper section can be estimated by taking the close of sedimentation at 1.74 cal kyr BP based on site C16. This gives a very rapid sedimentation rate of 9.2 mm/yr. If the close of the Sirini alluvium is taken at 2 cal kyr BP as indicated at site C4 then the rate blows out to 14.4 mm/yr. The rate for the whole section between, if taken as 3.1 - 1.74 cal kyr BP, would be 7.3 mm/yr which is very similar to the nearby site C3 (7.6 mm/yr). A clear picture emerges of very high sedimentation rates in the valley in the Early Iron Age to Roman periods.

**Leipsokouki alluvium**

The Leipsokouki alluvium was defined by Doyle (1990) and typically forms a 3-4 m thick alluvial deposit of sandy or gravelly channel type deposits covered with finer overbank deposits. Weak A/C soil profiles have developed on the alluvium. Deposits of alluvium that are 1-2 thick form part of the modern flood plain. These deposits are included in the definition of the Leipsokouki alluvium.
**Site C18 Leipsokouki alluvium near church of Panagia**

**Introduction and location**

This site is located in the central catchment area at latitude 40.1274° N and longitude 21.3744° E. This site has been sampled for charcoal at 0.55 m from the surface to provide dating for the Leipsokouki alluvium. The soils on the alluvium are weakly developed with incipient horizon expression e.g., P33, P31 of Doyle (1990).

Presented below is a summary of the key soil and sediment features, also refer to Tables 6.13 and 6.14 as well as Plates 6.18 and 6.19.

**Field stratigraphy**

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.35 m</td>
<td>1A1</td>
<td>Modern topsoil with strong pedality and few sub-angular to sub-rounded fine gravel fragments (1-6 mm) in finer soil matrix indicating a partly colluvial origin.</td>
</tr>
<tr>
<td>0.35 – 0.5 m</td>
<td>1C</td>
<td>Silty to fine sandy alluvium which exhibits fine bedding, however there are a few layers of coarse platy shaped gravels, they also have distinct bedding. Unit probably represents over-bank or slope wash as suggested by some fine gravel layers which could readily be derived from adjacent slopes.</td>
</tr>
<tr>
<td>0.5 – 0.8 m</td>
<td>2A1</td>
<td>Buried soil-like material with distinct bands of charcoal. Soil-like material with strong pedality and contains few angular and sub-angular gravels of 2-30mm size range suggesting a colluvial input from the adjacent slope. Material is radiocarbon dated to 0.55 cm to 140 ± 130 cal yr BP (see Figure 6.11, Wk9926).</td>
</tr>
<tr>
<td>0.8 – 1.5 m</td>
<td>2C</td>
<td>Fine-textured matrix with common angular gravel fragments set in a fine matrix suggesting colluvial nature of materials. Fine (1-2 mm) veins and coatings of calcium carbonate in pores and on gravel fragments. Many fine root pores. Matrix has weak pedality. Sorting and angular “floaters” suggest material is probably soil derived slope deposits.</td>
</tr>
</tbody>
</table>
1.5 – 3.5 m 3C  Well sorted, stratified, loose sand which appear alluvial. May be either over-bank or levee/crevasse splay type deposits.

3.5 – 4 m 4C  Well sorted, rounded and sub-rounded, clast-supported alluvial gravels, i.e., probably channel type deposits.

Table 6.14  Basic field morphological data for soil site C18

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Hor</th>
<th>Description</th>
<th>Texture</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev Ty Size</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.35</td>
<td>1A1</td>
<td>Modern colluvial topsoil</td>
<td>CLFS+</td>
<td>2.5Y 4 2</td>
<td>2.5Y 6 2</td>
<td>3 PO 2-10mm</td>
<td>3</td>
</tr>
<tr>
<td>0.35-0.5</td>
<td>1C</td>
<td>C horizon of modern soil</td>
<td>FSL</td>
<td>2.5Y 5 3</td>
<td>2.5Y 7 2</td>
<td>1 SB 10-20mm</td>
<td>3</td>
</tr>
<tr>
<td>0.5–0.8</td>
<td>2A1</td>
<td>Charcoal and ash in colluvial soil matrix</td>
<td>CLFS</td>
<td>2.5Y 4 1</td>
<td>2.5Y 5 2</td>
<td>3 PO 10-20mm</td>
<td>3</td>
</tr>
<tr>
<td>0.8-1.5</td>
<td>2C</td>
<td>Colluvial layer</td>
<td>CLFS</td>
<td>2.5Y 4 2</td>
<td>2.5Y 6 2</td>
<td>1 PO 20-50mm</td>
<td>2</td>
</tr>
<tr>
<td>1.5-3.5</td>
<td>3C</td>
<td>Sand alluvium</td>
<td>SCL-</td>
<td>2.5Y 5 2</td>
<td>2.5Y 7 2</td>
<td>0 SG</td>
<td>4</td>
</tr>
</tbody>
</table>

Tables 6.14 and 6.15 indicate the modern topsoil and the buried topsoil have stronger structure and lower pH values than other layers. This is consistent with the presence of organic matter. They also have darker moist soil colours and heavier textures than the C horizons. The 2.5Y hues and medium value and low chroma also indicate this. The soil materials at C18 also exhibit a moderate or strong reaction to 10% hydrochloric acid, except for the colluvial layer 2C, indicating weak leaching or recent mixing with more calcareous materials.

Table 6.15  Basic chemical data for soil site C18

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carbon (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC µS/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A1</td>
<td>0-0.35</td>
<td>Modern colluvial topsoil</td>
<td>1.11</td>
<td>8.0</td>
<td>354</td>
</tr>
<tr>
<td>1C</td>
<td>0.35-0.5</td>
<td>C horizon of modern soil</td>
<td>0.44</td>
<td>8.3</td>
<td>180</td>
</tr>
<tr>
<td>2A1</td>
<td>0.5–0.8</td>
<td>Charcoal and ash in colluvial soil</td>
<td>1.42</td>
<td>7.9</td>
<td>350</td>
</tr>
<tr>
<td>2C</td>
<td>0.8-1.5</td>
<td>Colluvial layer</td>
<td>0.60</td>
<td>8.4</td>
<td>220</td>
</tr>
<tr>
<td>3C</td>
<td>1.5-3.5</td>
<td>Sand alluvium</td>
<td>0.20</td>
<td>8.2</td>
<td>157</td>
</tr>
</tbody>
</table>

The topsoil horizons (1A1, 2A1) have soil pH 8.0 or lower indicating weak leaching and low amounts of organic matter build-up. The soil pH is lower and the organic carbon levels are higher in the topsoil layers. These horizons also exhibit strong soil
Plate 6.18 Plate A above shows site C18 with soil and alluvial sediments forming the Leipsokouki alluvium, charcoal layer indicated gave modern age. Plate C below shows a view of the various alluvium and adjacent Sirini alluvium. Plate B shows a typical example of the weakly developed soil profile on the Leipsokouki alluvium (after Doyle 1990).
Figure 6.11 Radiocarbon calibration curves for sites C2 and C18 after Stuiver et al (1998) using the software of Bronk Ramsey (2002).
1A1  0 – 0.35 m
Modern topsoil, strong angular pedality (A), common sub-angular 2-60 mm lithic fragments in fine matrix (B, C) suggesting colluvial origin

1C  0.35 – 0.5 m
Weak pedality (A), highly calcareous, thin bedding (B) indicating alluvial nature of sediment, ferruginous coatings on some pores.

2A1  0.5 – 0.8 m
Strong pedality (A), poorly sorted, 2-30 mm, angular to sub-rounded lithic fragments in fine matrix (B, C) indicating material is colluvial in origin, radiocarbon dated to $140 \pm 130$ years BP at 0.55 m

2C  0.8 – 1.5 m
Matrix with weak pedality (A), angular to sub-rounded gravels 2-30 mm (C) set in fine matrix – suggests colluvial origin, calcium carbonate lining pores and coating gravels

4C  1.5 – 3.0 m
Rounded to sub-rounded coarse sand and fine gravel with distinct stratification (B) and moderate sorting indicate the material is of alluvial origin, some re-deposition of calcium carbonate along pores (C)

Plate 6.19 Micrographs of site C18 (scale increment is 1 mm).
structure. This is probably related to their origin as pedogenic colluvium and also the abundance of reactive clay minerals in the catchment. These minerals aid shrinking and swelling and thus structural development.

The incipient characteristics of the soils, in particular the absence of B horizons, is in accordance with the findings of Doyle (1990) where soil profiles developed on the Leipsokouki alluvium such as P29, P31, P33, P50 and P55 all lacked B horizons and are essentially thin topsoils over alluvium i.e., A/C soils. The alluvium consists of fine textured over-bank sediment over water worn, clast-supported gravels that are more typical of channel deposits. These gravels contain water-worn fragments of pottery, typically well-fired and Historic ((Ottoman, Roman, Hellenistic, and Early Bronze Age).

**Chronology**

Charcoal taken at 0.55 m has provided an age of $140 \pm 130$ cal yr BP (Wk9926 calibrated date 95% confidence) i.e., modern. This date is younger than expected as the alluvium was thought to have accumulated over the last 500 years based on the weak soil development on the alluvium (Doyle 1990). However, the date is for colluvium that buries the Leipsokouki alluvium and hence the prior age estimate may not be too wide of the mark. The alluvium requires more dated sites that could not be found during the fieldwork. Doyle (1990) noted the basal gravels of these deposits contain a mixture of Hellenistic, Roman, Byzantine and Ottoman sherds. The presence of the Ottoman sherds indicates the alluvium must be younger than 500 years BP.

**Interpretation**

The sedimentary sequence at site C18 indicates water-worn alluvial gravels capped by sandy overbank or levee/splay deposits. Colluvial material with more angular lithic fragments and soil-like materials cap the alluvial part of the section. This material could easily be derived from the adjacent slope.

The Leipsokouki alluvium must represent a period of instability in the catchment vegetation cover or erosion rate, leading to greater sediment supply and localised aggradation. This alluvium, which forms at two distinct levels, is inset into the older
and more substantial Sirini alluvium. The modern stream has re-incised into both these alluvial deposits. Sites C18, P29, P31, P33, P50 and P55 indicate the Leipsokouki alluvium is generally composed of a gravelly base (channel-deposit) of clast-supported, water worn gravels capped by 0.5-1 m of finer alluvium. The soils are highly calcareous and alkaline indicating little or no leaching.

If the maximum height of the Leipsokouki alluvium is 3.5 m and the material is no older than Ottoman a very tentative sedimentation rate is 7 mm/yr. This is very similar to the rates obtained for the Sirini Alluvium at C3, C16 and P52.

**Summary of mid-late Holocene alluvial deposits**

It has been determined that alluvial deposition of gravels, sands and silts has occurred in the valley floor between approximately 5,900 and 1,700 cal yr BP and then again after about 500 years BP. Pauses in this sedimentation occur between 4,400 and ca 4,150 cal yr BP and also prior to 3,100 cal yrs BP. These alluvial sediments are inter-bedded with colluvial sediments and soil horizons. It seems the early Holocene was a period of valley incision as no alluvial deposits where found dating to between about 6,000 and 9,000 cal yrs BP. This situation suggests stream power was sufficient to remove any sediment from the valley in this early Holocene period. This notion is supported by the well-developed soil profiles that occur on the Syndendron alluvium which was deposited between 14,500 and 9,000 cal yr BP (refer to Chapter 5).

Wilson *et al* (2000) indicate that rainfall was higher in the early to mid Holocene in the Sahel (6-9 kyr BP). This is support by findings in the Adriatic Sea cores (*Ariztegui et al*. 2000). In the Leipsokouki valley soil creep, soil formation and stream incision at this time support the notion of greater tree cover associated with the warmer and moister conditions. Thus the alluvial events in the Leipsokouki valley after *ca.* 6,000 cal yr BP coincide with both the initiation of agriculture in the Neolithic and the close of the post glacial optimum climatic conditions. The sedimentation rate between 5,880 and 4,380 cal yr BP are relatively consistent at 1.2 mm/yr, although no allowance for two periods of soil formation has been allowed. (see Table 6.16). If each soil had taken approximately 500 years to develop then rate triples to 3.5 mm/yr.
Table 6.16  Sedimentation rates for the Amygdalies Alluvium

<table>
<thead>
<tr>
<th>Site</th>
<th>Thickness of alluvium (m)</th>
<th>Start time (kyr)</th>
<th>End time (kyr)</th>
<th>Period of deposition (kyr)</th>
<th>Sedimentation rate (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C8 upper</td>
<td>0.45</td>
<td>4.69</td>
<td>4.38</td>
<td>0.31</td>
<td>1.5</td>
</tr>
<tr>
<td>C8 mid</td>
<td>0.6</td>
<td>5.30</td>
<td>4.69</td>
<td>0.61</td>
<td>1.0</td>
</tr>
<tr>
<td>C8 base</td>
<td>0.7</td>
<td>5.88</td>
<td>5.30</td>
<td>0.58</td>
<td>1.2</td>
</tr>
<tr>
<td>C8 Total</td>
<td>1.75</td>
<td>5.88</td>
<td>4.375</td>
<td>1.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

The sedimentation rates for the Sirini and Leipsokouki alluvial deposits are presented in Table 6.17. The table indicates that at site C14 sedimentation began at after 4,150 years BP but at all other sites after 3,100 years BP. Deposition at C14 pauses sometime in the pre-Classical (ca. 500 BC) and a soil develops. The alluvium below and above this undated soil are called the Sirini A and Sirini B alluvia respectively. The sedimentation rate after 3,100 years is commonly in the order of 6 - 8 mm/yr the highest yet seen in the valley. This dramatic acceleration in sedimentation rate coincides with the onset of the Early Iron Age which was a time of markedly increased human activity in the valley (Wilkie 1995).

Table 6.17  Sedimentation rates for the Sirini and Leipsokouki deposits

<table>
<thead>
<tr>
<th>Site</th>
<th>Thickness of alluvium (m)</th>
<th>Start time (kyr)</th>
<th>End time (kyr)</th>
<th>Period of deposition (kyr)</th>
<th>Sedimentation rate (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C14</td>
<td>5.2</td>
<td>4.15</td>
<td>2.00</td>
<td>2.15</td>
<td>2.4</td>
</tr>
<tr>
<td>C4</td>
<td>2.6</td>
<td>3.10</td>
<td>2.01</td>
<td>1.09</td>
<td>2.4</td>
</tr>
<tr>
<td>C3</td>
<td>7.8</td>
<td>3.03</td>
<td>2.00</td>
<td>1.03</td>
<td>7.6</td>
</tr>
<tr>
<td>C16</td>
<td>8.1</td>
<td>3.06</td>
<td>1.74</td>
<td>1.32</td>
<td>6.1</td>
</tr>
<tr>
<td>C16 upper</td>
<td>1.5</td>
<td>2.30</td>
<td>1.74</td>
<td>0.56</td>
<td>2.7</td>
</tr>
<tr>
<td>C16 lower</td>
<td>6.4</td>
<td>3.06</td>
<td>2.30</td>
<td>0.77</td>
<td>8.4</td>
</tr>
<tr>
<td>P52 Upper</td>
<td>6.5</td>
<td>2.45</td>
<td>1.74</td>
<td>0.71</td>
<td>9.2</td>
</tr>
<tr>
<td>P52 Lower</td>
<td>3.0</td>
<td>3.06</td>
<td>2.45</td>
<td>0.61</td>
<td>4.9</td>
</tr>
<tr>
<td>P52 Whole</td>
<td>9.6</td>
<td>3.06</td>
<td>1.74</td>
<td>1.32</td>
<td>7.3</td>
</tr>
<tr>
<td>C18</td>
<td>3.5</td>
<td>0.50</td>
<td>0</td>
<td>0.5</td>
<td>7.0</td>
</tr>
</tbody>
</table>
CHAPTER 7  Holocene slope deposits and review of key sites from Doyle (1990)

Site C1 - Tsifliki

Introduction and location

This section is exposed along a newly built road in the upper catchment at latitude 40.1372° N and longitude 21.3576° E and is 350 m south of Tsifliki. The section exposes up to 4 m of slope deposits. The site lies 8-10 m above a major tributary of the Leipsokouki stream on a steep slope (20-30%). The deposit consists of at least two debris flow deposits, the upper is composed of large blocks of brown soil that have travelled down slope encased in a bouldery, greyish debris flow deposit. Beneath this is a soil-like layer containing charcoal that caps more debris flow materials. Plates 7.1 and 7.2 and Figure 7.1 show site C1 and its location while Tables 7.1 – 7.3 and Plate 7.3 provide information of the sample characteristics.

Field stratigraphy

Depths are approximate and vary laterally across the section (see Plate 7.1)

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.6 m</td>
<td>1A1 Modern colluvial soil, moderately developed pedality (5-20 mm) dark brown in colour, many angular stones and boulders (up to 600 mm dia.) in earthy matrix, material is a soil-like colluvium (not sampled).</td>
</tr>
<tr>
<td>0.6 – 1.8 m</td>
<td>2BC Light olive brown silt loam forming a fine matrix with common angular stones and boulders floating in matrix interpreted as debris flow deposit (not sampled as has similar matrix to material below).</td>
</tr>
<tr>
<td>1.8 – 2.8 m</td>
<td>2B2/2BC The debris flow deposits as above with angular boulders, stones and some gravel in a silty loam matrix, but with large pieces of non-calcareous, highly pedal, brown soil profile (0.5 x 1.5 m in dia.) encased in the debris flow materials. The larger intact pieces of soil have common coarse roots suggesting soil matrix is fertile and/or moisture retentive (see Plate 7.1).</td>
</tr>
<tr>
<td>2.8 – 2.85 m</td>
<td>3A1 Dark greyish brown, moderately structured, contains common angular stones and gravels indicating this soil-like material is</td>
</tr>
</tbody>
</table>
probably colluvial in origin. Charcoal sampled for radiocarbon dating provided an age of 6,550 ± 350 cal yr BP (see Figure 7.1, Wk9812).

2.85 – 3.8 m 3BC Debris flow deposit, common angular stones and gravels set in a silty clay loam matrix. Thus the depositional sequence is:- IN-DF-COSO-DF-COSO.

**Basic chemical properties**

Tables 7.1 and 7.2 indicate the debris flow matrix materials (2BC and 3BC) are highly calcareous and alkaline. The large pieces of brown soil-like material (3B2) are encased within the stony debris flow deposit (3BC). They have a stronger soil structure than the other materials in the section. These brown soil materials are also leached of carbonate (no reaction to dilute HCl) and are lower in soil pH than other materials in the section, supporting the notion they are intact pedogenic materials.

<table>
<thead>
<tr>
<th>Hor</th>
<th>Depth (m)</th>
<th>Description</th>
<th>Text</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2BC</td>
<td>1.8-2.8</td>
<td>Greyish brown debris flow</td>
<td>ZL+</td>
<td>2.5Y 5 3</td>
<td>2.5Y 7 2</td>
<td>0 SG</td>
</tr>
<tr>
<td>2B2</td>
<td>1.8-2.8</td>
<td>Brown soil within debris</td>
<td>ZLC</td>
<td>7.5YR 4 3</td>
<td>10YR 6 4</td>
<td>3 PO 2-10mm</td>
</tr>
<tr>
<td>3A1</td>
<td>2.8-2.85</td>
<td>Thin topsoil with charcoal</td>
<td>ZLC-</td>
<td>2.5Y 4 2</td>
<td>2.5Y 6 2</td>
<td>2 PO 2-20mm</td>
</tr>
<tr>
<td>3BC</td>
<td>2.85-3.8</td>
<td>Debris flow material</td>
<td>ZCL</td>
<td>5Y 6 3</td>
<td>5Y 8 2</td>
<td>0 MA</td>
</tr>
</tbody>
</table>

Table 7.2 indicates the soil-like material (3A1) exhibits higher organic carbon levels and has a lower pH than both the debris flow materials (2BC and 3BC). The encased reddish brown soil material (2B2) has the lowest soil pH as might be expected of weathered soil materials. The organic carbon content is low but this may be due to the fact that it is subsoil material. The 2B2 also exhibits the lowest electrical conductivity. However the electrical conductivity levels of all the samples is low (<215 μS/cm).

<table>
<thead>
<tr>
<th>Hor</th>
<th>Depth (m)</th>
<th>Description</th>
<th>Organic Carbon</th>
<th>pH 1:5 soil:water</th>
<th>EC μS/cm</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>2BC</td>
<td>1.8-2.8</td>
<td>Greyish brown debris flow</td>
<td>0.84</td>
<td>8.1</td>
<td>215</td>
<td>4</td>
</tr>
<tr>
<td>2B2</td>
<td>1.8-2.8</td>
<td>Brown soil within debris</td>
<td>0.78</td>
<td>7.7</td>
<td>152</td>
<td>0</td>
</tr>
<tr>
<td>3A1</td>
<td>2.8-2.85</td>
<td>Thin topsoil with charcoal</td>
<td>1.13</td>
<td>7.9</td>
<td>192</td>
<td>3</td>
</tr>
<tr>
<td>3BC</td>
<td>2.85-3.8</td>
<td>Debris flow material</td>
<td>0.51</td>
<td>8.5</td>
<td>145</td>
<td>4</td>
</tr>
</tbody>
</table>
Plate 7.1 Photographs A above and B below show site C1 near Tsifliki. The section shows a younger debris flow deposit with large whole pieces of brown soil profile capping a dated thin soil layer (6,550 ± 350 years BP - Wk9812 calibrated age) this soil layer caps a second light grey debris flow deposit.

Figure 7.1 Radiocarbon calibration curve for C1 after Stuiver et al (1998) and software from Bronk Ramsey (2002).
Plate 7.2 Plate A above is approximately 30 m up road cutting from site C1. Plate A shows large pieces of reddish brown soil set in a light grey debris flow deposit. Plate B below shows site C1 with younger fill lying above an older light grey debris flow deposit. The two flows are separated by a dated soil at 6,550 ± 350 years BP (calibrated Wk9812)
Plate 7.3 Micrographs of the soil and sedimentary materials from site C1 (scale in mm)

**2BC 1.8-2.8 m**
Debris flow matrix (A), aggregates (B) and angular lithic fragments (C), highly calcareous

**2B2 1.8-2.8 m**
Soil material incorporated within debris flow deposit, strong angular pedality (A-C), non-calcereous, earthy brown colour, smooth surfaces on some ped faces (C)

**3A1 2.8-2.85 m**
Buried topsoil material with moderate angular pedality (B-C), common charcoal fragments (A) and rounded to sub-angular lithic fragments (A, C)

**3BC 2.85-3.8 m**
Calcareous debris flow matrix (A), with flaky fabric (B, C) and calcareous fragments (from eroded subsoils?)
**Plate 7.4** ESEM micrograph of brown soil material (2B2) entrained in debris flow at site C1. The micrograph of 2B2 soil matrix shows the soil has strongly coherent smooth ped fabric with strong aggregation of the minerals present.

**Figure 7.2** ESEM spectra of matrix of brown soil shown in plate above, the spectra indicates strong peaks for Al, Si, O, Mg, K and Fe. These elements are the building blocks of the minerals quartz, smectite, mica, chlorite and plagioclase. The Fe peak may reflect amorphous or crypto-crystalline iron oxides apparent from the distinct brown to reddish brown soil hues but not shown by the XRD analysis.
Plate 7.5 Soil profile P41 from Doyle 1990 showing the growth of many coarse roots in a piece of well-structured brown soil in debris flow matrix. This site indicates the possibility of the broad slope wide extent of the debris flow deposit C1.

Figure 7.3 Location of site C1 Soil profile P41 from Doyle 1990.
XRF and XRD analysis

It can be seen from Table 7.3 that the brown soil materials (2B2), which are encased in the upper debris flow material, contain higher iron, silica, aluminium, potassium, and titanium oxides. These are features of more weathered soil materials that are high in clay minerals. The alumino-silicate minerals (smectite, mica and chlorite) contain greater amounts of aluminium, potassium and silica. Calcium and magnesium oxides are far higher in the debris flow materials and basal debris flow which supports the idea of these encasing materials being younger and derived from calcareous - less weathered bedrock derived materials. This supports the notion that the encased brown soil was carried as partly intact pieces of soil profile within a semi-fluid debris flow.

The buried topsoil horizon (3A1) which separates the two parts of the debris flow has similar XRF characteristics (see Table 7.3) to the soil material entrained in the debris flow i.e., higher silica, aluminum, iron and sodium oxides. These properties suggest it is derived from soil-like material via colluvial processes.

Table 7.3  Whole soil X-ray fluorescence (%) for site C1

<table>
<thead>
<tr>
<th>Horizon</th>
<th>SiO$_2$</th>
<th>TiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>Fe$_2$O$_3$</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
<th>P$_2$O$_5$</th>
<th>Loss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2BC 1.8-2.8 m</td>
<td>28.72</td>
<td>0.30</td>
<td>6.27</td>
<td>4.70</td>
<td>0.05</td>
<td>7.95</td>
<td>24.27</td>
<td>0.78</td>
<td>1.11</td>
<td>0.12</td>
<td>25.31</td>
<td>99.58</td>
</tr>
<tr>
<td>2B2 1.8-2.8 m</td>
<td>57.82</td>
<td>0.74</td>
<td>16.27</td>
<td>8.49</td>
<td>0.09</td>
<td>4.37</td>
<td>1.19</td>
<td>1.53</td>
<td>3.16</td>
<td>0.06</td>
<td>6.75</td>
<td>100.46</td>
</tr>
<tr>
<td>3A1 2.8-2.85 m</td>
<td>50.06</td>
<td>0.62</td>
<td>12.75</td>
<td>6.84</td>
<td>0.09</td>
<td>5.81</td>
<td>8.13</td>
<td>1.40</td>
<td>2.71</td>
<td>0.12</td>
<td>11.50</td>
<td>100.03</td>
</tr>
<tr>
<td>3BC 2.85-3.8 m</td>
<td>29.76</td>
<td>0.35</td>
<td>7.33</td>
<td>4.80</td>
<td>0.06</td>
<td>6.60</td>
<td>24.34</td>
<td>0.89</td>
<td>1.45</td>
<td>0.13</td>
<td>23.98</td>
<td>99.69</td>
</tr>
</tbody>
</table>

Table 7.4 shows the whole soil X-ray diffraction data at the site and they indicate the debris flow materials (2BC and 3BC) are dominated by the mineral calcite, in this case “free” lime or calcium carbonate (note very strong reaction to dilute HCl Table 7.1) with moderate smectite and minor mica. They (2BC and 3BC) also have a very high “loss” value which probably relates to water and carbon losses associated with the calcium carbonate. The brown soil material (2B2) is quite different, being dominated by quartz and smectite with moderate mica and chlorite levels, a clear indication of its greater degree of weathering. The buried topsoil (3A1) is somewhat intermediate in composition with moderate levels of smectite and mica with lesser amounts of quartz and chlorite. The 2B2 horizon also contains the mineral palygorskite which suggests high magnesium and possibly a saline environment of
formation (Read 1947). Although no saline environment exists in the region the presence of calcite and serpentine indicates a high soil pH and magnesium rich environment for the preservation and/or formation of speolite and palygorskite. However the study and also Doyle (1990) have indicated loess beds are a component of the upper slopes and catchment divide (see Figure 4.3 and Plate 4.6). Thus it may be the palygorskite is derived from the aeolian accession from remoter sources.

Table 7.4 Whole soil X-ray diffraction data for site C1

<table>
<thead>
<tr>
<th>Horiz</th>
<th>25%-35%</th>
<th>15%-25%</th>
<th>10-15%</th>
<th>5%-10%</th>
<th>2%-5%</th>
<th>&lt;2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2BC</td>
<td>Calcite</td>
<td>Smectite</td>
<td>Mica</td>
<td>Qtz., Chl., Serp., Dolo.</td>
<td>Plagioclase</td>
<td>Talc</td>
</tr>
<tr>
<td>3BC</td>
<td>Calcite</td>
<td>Smec., Mica</td>
<td>Chlorite</td>
<td>Quartz</td>
<td>Serp., Dolo., Plag.</td>
<td>K-Feldspar, Talc</td>
</tr>
</tbody>
</table>

Chronology
Charcoal taken from the topsoil layer at 2.8 m from the modern soil surface provided an age of 6,550 ± 350 cal yr BP (Wk9812 see Figure 7.1). This date indicates the upper part of the debris flow is younger than 6,600 cal yr BP while the lower part is somewhat older than this. The fact that both have similar characteristics and the fact the buried soil is very thin and weakly developed suggests the lower part of the debris flow is not likely too much older than 6.6 cal kyr BP. The upper part of the debris flow may relate to the burning of the slope as indicated by the charcoal in the 3A1 topsoil. In summary it would appear the two deposits are likely to be similar in age and a part of the same general period of slope instability. The upper debris flow deposit thus coincides with the Middle Neolithic and the lower debris flow probably to the early Mid Neolithic or the Early Neolithic period. While the Early Neolithic was an important period in Grevena the Middle Neolithic was less so (Wilkie and Savina 1992; Wilkie and Savina 1997). Soil profile P41 indicates whole pieces of soil with intact root systems were part of the land sliding of this period (Plate 7.4).

Interpretation
One interpretation for this site is that stream incision during the period 9 – 6.5 cal kyr BP led to slope undercutting and thus aided de-stabilisation of the slope at C1. The debris flows have occurred as two distinct events separated by a topsoil layer,
probably of colluvial soil material (3A1). The C1 and also P41 sites represent erosion of both well developed soils and erosion of rocky regolith that requires fragments of bedrock to become entrained in the flow. This indicates the debris flows themselves must have induced some erosion, scouring and entrainment of bedrock fragments. Soil profile P41 (Doyle 1990) represents a debris flow deposited on a slope where no undercutting of the toe of the valley slope has occurred. This is taken as an indication that toe slope undercutting may not be the key cause of the debris flows in this area (see Plate 7.5 and Figure 7.3). The site also demonstrates that large pieces of intact soil profile, with many coarse roots, have become entrained in the debris flow deposits in this Tsifliki area. The coarse and abundant nature of the roots may indicate a tree cover had existed close to the time of the flow. Today the site is an open field.

Another interpretation is that the debris flow near Tsifliki may have been triggered by an earthquake or heavy rain storm event – particularly if vegetation clearance had occurred. Rassios (2004a), I.G.M.E. geologist in Grevena, has indicated only a few landslides were associated with the 1995 earthquake in the Nomos of Grevena, the largest at the village of Kentro. She states “I think …a year of torrential rain would probably set off as many landslides as an earthquake.” Rassios (2004) also indicates that epicenters of aftershocks from the 1995 earthquake were reported along the Grevena River valley, and that there ought to be a parallel buried fault further to the NE in the Leipsokouki valley. However no landslides occurred in the Leipsokouki valley during or immediately following the 1995 earthquake. While it is difficult to determine the actual cause of the particular mass movement at C1 three clues hint at excess water and loss of vegetation. Firstly the flow occurs as two large events separated by a thin colluvial topsoil horizon, which contains abundant charcoal. This indicates a break between the events rather than one event related to a single large earthquake. Secondly the charcoal in the thin colluvial soil indicates burning on the slope close to the time of the debris flows. Thirdly the flow must have been quite fluid to allow the large pieces of soil profile to float in the flow and maintain their integrity. This indicates the soil and regolith were moist and probably saturated. Closer examination of the intact soil profile pieces also suggests they are inverted with the topsoil face down and the subsoil above which itself is buried by debris flow.
matrix (Plates 7.1 and 7.2). The soil mineralogy indicates palygorskite, sepiolite, talc and smectite which are reactive, greasy minerals able to lubricate landslides.

**Review of Soil profile P40 (Doyle 1990)**

Soil profile P40 is located at latitude 40.13840° N and longitude 21.35160° E and is 500 m west of site C1 and 250 m upslope of the stream-line. The section shows stratified colluvial profile of P40 which was described and radiocarbon dated by Doyle (1990). The site is located in the upper catchment near Tsifliki (see Figure 7.6). Charcoal associated with a buried soil provided a radiocarbon date of $675 \pm 125$ cal yr BP (see Figure 7.4, Wk1486). This thin buried soil is capped by two colluvial deposits, one soil-like colluvium, the latter lighter and containing angular lithic fragments of shale. They indicate active slope disturbance after $675$ cal yrs BP. The charcoal rich and stone-free buried topsoil occurs at 80 –100 cm below the modern land surface. This is overlain by well-structured brown soil colluvium which was probably derived from erosion that occurred following the charcoal producing fire. The upper 25 cm of the profile is lighter coloured (greyer), incipient, weakly structured, with common angular pebbles of shale. The sedimentation record given by Chester (1991) from pollen cores near Grevena indicates widespread burning and high amounts of inorganic sediment deposition post 1320 AD. Chester also indicates that cereal cultivation was occurring in the Grevena region at this time.

This site indicates a period of relative landscape stability prior to $675 \pm 125$ cal yr BP during which time a weak colluvial soil developed. This was disturbed by fire resulting in two phases of colluvial transport. The first represents soil redistribution from the slopes above while the second phase represents slightly deeper seated erosion in which entrained lithic bedrock fragments form what must have been a partly exposed slope.

**Review of Soil Profile P11 (Doyle 1990)**

Soil profile P11 from Doyle (1990) represents a thick soil-like colluvium deposited in a prior fluvial channel (Plates 7.7 – 7.9 and Appendix 2). This soil colluvium contains many Iron Age and Early Iron Age pot sherds at 0.8 – 1.6 m from the surface (Wilkie and Savina 1992; Wilkie 1995). The site is in the mid catchment and lies below the hilltop site of Paleokastro. The dark brown, soil-like colluvium rests
Charcoal rich layer from soil P40 radiocarbon dated to 675±125 BP, calibrated Wk1486

Plate 7.6 Location (B) and soil profile of site P40 (A) from Doyle (1990). Plate A shows the soil profile and depth of radiocarbon date of 675 ± 125 years BP (calibrated Wk1486). Plate B show the location of the site with respect to P41 and C1.
Figure 7.4 Radiocarbon calibration curves for soil profiles P40, P11 and P47 after Stuiver et al (1998) and software from Bronk Ramsey (2002).

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abruptly on beds of water-worn gravels and stones with distinct imbrication and bedding (see Plates 7.8 and 7.9). The channel and associated gravels are cut into the underlying Syndendron alluvium and therefore represent and the Sirini A alluvium. The lower part of the soil-like colluvium is dated at 2,750 ± 600 cal yr BP and falls within the Iron Age period (Figures 7.4 and 7.5). This concurs with the pot sherds found within the deposit. The bulk of the soil colluvium has been leached of any calcium carbonate and there is an accumulation of carbonate at the basal part of the deposit. The deposit highlights that gullying in this landscape must have commenced prior to about 2,750 cal yr BP as the coarse gravelly alluvium requires erosion of bedrock and this is most likely to occur during gully cutting in side-valleys. Following the deposition of the gravelly alluvium, the surrounding slopes acted as a source of soil-like colluvium which was then transported into topographic hollows. The site also indicates moderately well developed dark, well-structured soils covered the surrounding slopes at about 2,750 cal yrs BP.

**Review of Soil Profile P47 (Doyle 1990)**

This site occurs on a steep slope at Paleokastro in the mid catchment area at latitude 40.12790° N and 21.36720° E (refer to Plate 7.10, Figure 7.5 and Appendix 2). The deposit itself rests in a bedrock gully and thus the site clearly demonstrates that the gullying processes in the catchment were active prior to 2,175 ± 175 cal yr BP (Wk1586, see Figure 7.4). The deposit is composed of highly calcareous regolith materials with clear stratification suggesting the materials represent a series of colluvial deposits (3-4 events). The basal materials are more compact and paler in colour than the mid part of the section which is slightly darker and contains more angular stone fragments. The section is capped by recent soil-like colluvium. Overall the site appears to represent sediment derived from denuded soils and regolith. That is to say the deposit lacks the typical very dark brown to black soil colours, strong pedality and silty clay or silty clay loam texture of the older colluvial deposits in the valley. The site indicates the loss of the very dark brown soils typical of the surrounding slopes (Doyle, 1990) had occurred prior to approximately 2,200 cal yrs BP. The gully initially was filled by fine calcareous regolith prior to being filled with calcareous soil-like colluvium. Hellenistic sherds occur throughout the lower 1 m of the section while the upper 1 m has a mixture of Hellenistic, Roman and Byzantine
Figure 7.5 Soil profiles P11 and P47 from Doyle 1990.

Plate 7.7 Site P11 from Doyle (1990) with the site of Paleokastro behind.
Plate 7.8 Soil profile P11 from Doyle (1990) dated near the base of the brown soil-like colluvial fill at 2,750 ± 600 years BP (calibrated Wk1483). Note alluvial gravel deposits on far left of photograph. These gravels form in a depression cut into the Syndendron alluvium.

Plate 7.9 Site P11 from Doyle (1990) showing alluvial deposits inset into gully cut across the Syndendron alluvium, brown soil-like colluvial fill to the right dated at 2,750 ± 600 years BP (calibrated Wk1483) near its base.
Plate 7.10 Soil profile P47 from Doyle (1990) dated near the base of the stratified colluvial fill at 2,175 ± 175 years BP (calibrated Wk1586). This indicates active gullying prior to 2.2 Ka BP. Plate B below shows the section without unit delineations and with the archeological materials from the various units.
pot sherds (Wilkie and Savina 1992). The high number of Hellenistic sherds, bones, ash, rock fragments and calcareous sediment indicate this part of the landscape was intensively utilised at the time.

**Review of Soil Profile P36 (Doyle 1990)**

Soil profile P36, in the mid catchment 2 km west of Mega Sirini, indicates colluvial activity continued in the late Roman – early Middle Age period (see Figure 7.6, Plate 7.11 and Appendix 2). The site is located at latitude 40.12080° N and longitude 21.38900° E. The site shows a palaeochannel cut into a deposit of fine-textured alluvium, probably the Syndendron alluvium. This palaeochannel has been filled with calcareous fine-textured colluvium. Charcoal from a soil-like colluvial layer, at the base of the depression gave a radiocarbon date of 1,390 ± 90 cal yr BP (calibrated Wk1484, see Figure 7.7). The main body of the colluvium, although calcareous and greyish brown in colour, has moderate soil structure and fine texture. A similar greyish brown, fine-textured and calcareous colluvium caps site P59 (located 300 m north, see below).

These deposits suggest that by about 1,400 cal yr BP the surrounding slopes had become stripped of darker, less calcareous soil materials and instead more calcareous subsoil materials were providing the colluvium on many slopes in the valley. A similar type of calcareous greyish brown colluvium was produced at P47. These sites suggest the soils in many parts of the catchment may have become degraded by about 2 cal kyr BP.

**Review of Soil profile P59 above Syndendron alluvium**

Site P59 occurs in the mid catchment 300 m north of site P36 at latitude 40.12360° N and longitude 21.38920° E (see Figure 7.6). The section has a complex stratigraphy (see Plate 7.12). The most striking feature of the site is a well-structured, very dark to black, silty clay buried soil. This buried soil is covered by a thin layer of fine textured slope wash and then over 2 m of rather homogenous, calcareous, fine-textured dark grey colluvium. The colluvium mantles the landscape as well as filling pre-existing depressions. This distinct dark soil was radiocarbon dated to 5,065 ± 225 cal yr BP (Wk1582, see Figure 7.7). The origin of this dark soil appears to be colluvial as its thickness varies laterally and it has an abrupt lower boundary. At one point
Plate 7.11  Soil profile P36 from Doyle (1990) dated as indicated above at the base of the stratified colluvial fill which caps the Syndendron alluvium. The radiocarbon dating indicated the colluvium was younger than 1,330 ± 90 years BP (calibrated Wk1484).

Figure 7.6  Soil profiles P36 and P59 from Doyle 1990.
Figure 7.7 Radiocarbon calibration curves for soil profiles P36 and P59 after Stuiver et al. (1998) and software from Bronk Ramsey (2002).
Plate 7.12 Soil profile P59 showing very dark brown vertisol soil on Syndendron alluvium dated to 5,065±225 BP (calibrated Wk1582). The dark vertisol is likely to be colluvial as indicated by the abrupt lower boundary, highly variable profile thickness, the truncation of the thin soil shown below the spade handle and the evidence of an erosional surface provided by the paleo-channel in the left part of the section.

Figure 7.8 Location map of soil profile P59.
it truncates a thin underlying soil and in several places it appears to fill prior cut paleo-channels (see Plate 7.12). Below the soil is well stratified, fine-textured alluvium, which in combination with the radiocarbon date, suggest it is the Syndendron alluvium.

The site indicates erosion, namely the cutting of palaeochannels, occurred prior to 5,000 cal yrs BP. This was followed by redistribution of the dark soil colluvium. As the soil materials are dominantly reactive clay, the key redistribution mechanism was probably soil creep. Thus this site shows clearly the change in the nature of the soil colluvial materials from the period at about 5,000 cal yr BP to those of much younger age. Clearly loss of dark silty clay soils for many slopes in the period 5,000 to about 2,500 cal yr BP meant colluvial materials deposited after about 2,200 cal yr BP were more calcareous, much greyer in hue and commonly contained lithic fragments. In short they are derived from a partly degraded landscape.

**Review of Soil Profile P77 Bronze Age Soil Colluvium**

There are several undated colluvial deposits from Doyle (1990) that contain pottery fragments and thus indicate the maximum ages for colluvial activity. These include P58 which is a dark colluvial fill with Iron Age sherds 1.2 km WNW of Mega Sirini and P79 a buried soil with Early Bronze Age sherds 1 km E of Rodia. However only P77 will be more fully discussed here and the reader is referred to Doyle (1990) and Appendix 2 for the other sites. Soil profile P77 is a deep and dark pedogenic colluvium containing characteristic Middle Bronze Age sherds at 0.5 – 2 m depth (Wilkie and Savina 1992). This deposit occurs near the village of Syndendron at latitude 40.1323° N and longitude 21.3549° E. It provides a further example of the type of deep, non-calcareous dark soil-like colluvium that was transported into paleo-channels and depressions during the period of approximately 5,000 to 2,500 cal yrs BP. Two key questions such sites should raise are (i) why were the paleo-channels cut (many are in upper landscape positions) and (ii) why were they then so abruptly filled with colluvium. One possible explanation is a loss of part of the tree cover in parts of the landscape. This would allow for both greater amounts of run-off, thus allowing cutting of paleo-channels and secondly it would allow for greater movement of the soil mantle by soil creep processes.
Plate 7.13 Soil profile P77 (Doyle 1990) showing in the foreground light greyish stony soil (degraded) while in the mid-ground very dark soil occurs as a colluvial fill in a paleo-channel. This very dark brown soil has distinctive Middle Bronze Age pot sherds within it.

Plate 7.14 Soil profile P77 (Doyle 1990) showing very dark brown soil colluvium filling a paleo-channel. The colluvium contains distinctive Middle Bronze Age pot sherds (Wilkie and Savina 1992).
Site C15 Large gully throat

Introduction

Several major gullies exist in the mid catchment, in particular opposite and upstream of Mega Sirini. Several questions are raised when looking at these enormous landscape features i.e., when did they develop and why? Also why have they developed in some side valleys but not in others? Perhaps there is a threshold for gully initiation or perhaps they are related to human disturbance. Once a gully has been initiated it can migrate in a headward direction aided by the steep and denuded gully walls. The Tertiary mudstone/shale also has a fine fractured fabric that allows it to “fret” forming a fine grit and silty sediment which is readily transported in high stream flows. Site C15 was located in the throat of these gullies in an attempt to examine the soil stratigraphy at this important part of the landscape. The site is located at latitude 40.1177° N and 21.3933° S.

Field stratigraphy

Plate 7.16B shows a deposit of rounded gravels and stones, many with a distinct brown weathering rind, deposited against a steep slope cut into the marl bedrock i.e., they mark a steep erosional contact. The location of this deposit indicates the extent of the gully at the time of their deposition. These gravels can be traced up to 8-10 m above the modern streambed. Charcoal was sampled at 3.5 m from the soil surface and 4.0 m above the stream base.

The modern geomorphology gives clues as to the size and shape of the initial gully at the site. Plate 7.15A and Figure 7.9 show the cirque shaped valley which would have existed prior to the headward migration it has undergone since while Plates 7.16 A and B show the sloping erosional contact.

Table 7.5 Field and laboratory analysis of sample from C15

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Description</th>
<th>Field Text.</th>
<th>Moist Colour</th>
<th>Dry Colour</th>
<th>Structure Dev Ty Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>3.5-3.6</td>
<td>Ashy soil layer at throat of large gully</td>
<td>Humic ZCL</td>
<td>2.5Y 3</td>
<td>2.5Y 5</td>
<td>0.5 AB 20-50mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hor.</th>
<th>Depth (m)</th>
<th>Unit description</th>
<th>Organic Carb. (%)</th>
<th>pH 1:5 soil:water</th>
<th>EC mS/cm</th>
<th>HCl React</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>3.5-3.6</td>
<td>Ashy soil layer at throat of large gully</td>
<td>1.50</td>
<td>7.9</td>
<td>218</td>
<td>4</td>
</tr>
</tbody>
</table>
Charcoal was collected at this site for radiocarbon dating; however, as the exact setting of the deposit could not be determined, the sample has not been dated due to cost. It may be undertaken in the future.

**Summary**

Chapter 7 has demonstrated that a wide range of slope deposits occur in the valley. Chapters 4, 5, and 6 also covered soil slope deposits as they related to the catchment divide cover-beds, the Syndendron, Amygdalies, Sirini, and Leipsokouki alluvial units. The slope sediments include debris flows, soil colluvium, slope wash and soil creep materials. They range in age from 15 kyr to modern in age. This suggests the slopes within the valley have been active since at least the late glacial climatic optimum. The slope deposits are at almost all sites associated with charcoal or cultural artefacts. This suggests fire and associated loss of vegetative cover has been a key factor affecting slope transport. The abundance of cultural artefacts in soil colluvial deposits since the approximately the Early Bronze Age is suggestive of an anthropogenic role during the last 5,000 years. The older colluvial deposits often are dark coloured, non-calcareous and exhibit soil structure and other pedogenic features. Those colluvial deposits younger than ca. 2,500 years are calcareous, greyish or tan in colour and have weak pedogenic characteristics. This can be taken to suggest a significant loss of soil cover between about 2 – 3 kyr BP. It is during this time that the most dramatic and rapid alluvial sedimentation was occurring in the valley. This suggests hillslope erosion must also have been accelerated and thus acted as a source of sediment for the alluvial filling in the valley floor. As the erosion rate reduced, after ca. 2 kyr BP colluvium filled slope depressions and covered lower slopes and terraces. This left a landscape of eroded mid and upper slopes and a sequence of colluvium filled depressions in the landscape.
Plate 7.15 A – view of two large gullies in the mid catchment. B – location of site C15 is in the lower neck of the right-hand gully. Just why one side-valley develops into a gully while an adjoining one does not may be due to a geomorphic threshold or difference in human activity or land use.

Figure 7.9 Location of site C15 (contour interval is 4 m). Note the area around C15 has developed a gully yet the stream on the left has not. Blue dash line indicates the cirque shape the valley would have had prior to gully development.
Plate 7.16 Site C15  Upper photo shows the “Big Gully” ash and charcoal rich layer deposited at gully opening. Below note gravels overlying Tertiary strata at mouth of gully. Gravels in this position must pre-date the gully development, i.e., gully has been cut into gravels deposited on a pre-existing slope.
CHAPTER 8 Discussion of deposition and erosion history

Introduction

The Leipsokouki valley provides an excellent study location for developing an understanding of the history of soil erosion and alluviation in the Mediterranean. This is because the valley is narrow and there is thus a strong relationship between the valley slopes and the valley floor aggradation. In addition the valley has a weak substrate which provides ample sediment and there is an excellent history of human habitation extending from the Upper Palaeolithic to modern times.

Figures 8.1, 8.3 and 8.4 provide summaries of all the dating of alluvial and slope deposits in the valley over the last 15,000 years. Tables 8.1 and 8.2 provides brief descriptions, dates and archaeological information for all the alluvial and slope deposits units within the catchment. In this chapter these figures will be compared to climatic records, other Mediterranean studies and the archaeological record in an attempt at deciphering the likely factors controlling soil erosion and alluvial and colluvial deposition.

Pre 15 kyr BP catchment landscape and land resources

A key sedimentary feature of the Leipsokouki catchment is the location of deep loess and paleosol sequences on the drainage divides. They have provided a large volume of fine-textured sediment for more recent depositional materials in the lower slopes and valley floor, in particular the Syndendron alluvium and associated slope deposits. In the upper and mid catchment these loess-paleosol cover beds overlie moderately dipping inter-bedded Tertiary calcareous mudstones and fine-grained sandstones. The contact between the cover beds, and also fractures and bedding planes within the Tertiary strata, provide natural seepage points for groundwater, which are highly suited to stock and human needs. Rassios (2004b) indicates the contact of the Plio-Pleistocene sediments on the Tertiary strata represents the major aquifer in the region. Thus the landscape setting, on the ridge tops and upper slopes, is one of deep fine-textured soil materials and a good supply of perennial springs in the upper and mid catchment areas.
The fact that deep, fine-textured, calcareous loess cover-beds accumulated on much of the catchment divide (CDS1 – CDS4) and well developed soils formed on the mid-upper slopes (C7, CDS3, P38, P60, P63 and P81) during the late Pleistocene indicates these landscape components were relatively stable for considerable periods. Loess and paleosol sequences have been widely reported in neighbouring parts of the Mediterranean and southern Europe (Kostic and Protić 2000; Günster et al. 2001; Gvirtzman and Wieder 2001).

The lower slopes of the valley had mottled, moderately developed soils in the late Pleistocene, *Inceptisols* under US Soil Taxonomy (Soil Survey Staff 1992). The profiles exhibit very dark well-developed topsoils and have mottled and moderately structured, but otherwise weakly expressed B horizons e.g. C6, C13, and C19. The subsoils lack strong brown colouration and are not leached of carbonates. The pale olive colouration may partly be a factor of the calcareous parent materials and the weak leaching environment. These soil materials are colluvial in origin, as indicated by sub angular lithic gravels and stone fragments, and they indicate slope process were active in the period prior to the deposition of the Syndendron alluvium.

This then was the setting for Late Palaeolithic man to enter after approximately 15,000 cal yrs BP. But just when humans first entered the Grevena region has not been fully established (Wilkie and Savina 1992). The closest dated sites are in Epirus, they suggest it may have been after 17 kyr BP (Bailey et al. 1999; Woodward and Goldberg 2001; Woodward et al. 2001). The vegetation cover would have been dominantly grassland steppe (Bottema 1974; Willis 1992a; Willis 1992b; Roberts 1998) with good open viewing points providing security and hunting vantages, excellent spring water and ample materials for tool manufacture sourced from the chert and diabase that occur in the Plio-Pleistocene gravel beds. Morgan (1977) has shown that the loss of grassland cover on sandy soils on steep slopes increased erosion 20 fold (0.68 t/ha/yr to 18 t/ha/yr). The introduction of fire to the steppe vegetation cover on the steep slopes in the mid and upper Leipsokouki valley may have caused similar abrupt increases in soil erosion (chapter 5 sites C6, C12, C13, and C19).
Post 15 kyr landscape processes in the Leipsokouki

A range of accelerated landscape processes occur in the catchment after approximately 15 cal kyr BP. These include; slope wash, various forms of mass movement, alluvial deposition, gully development and steam incision and soil creep. These erosion/deposition events were separated by short periods of soil development. Tables 8.1 and 8.2 provide a summary of the deposits, radiocarbon dates, properties of the units and the archaeological information.

Role of fires on landscape processes in the Leipsokouki

Sites C6, C11, C12, C13, and C19 all indicate fire was an important modifying factor of the late Pleistocene landscape of Grevena. The presence of Upper Palaeolithic tools in the Grevena region and the identification of such tools in the Leipsokouki catchment indicate humans were present in the area at a time when fires were occurring (Wilkie and Savina 1992; Wilkie 2004). Samples taken from buried mature soils and late Pleistocene paleosols on the catchment divides and upper slopes do not contain charcoal. Charcoal was not observed during the field examination of 50 m of exposed Plio-Pleistocene paleosols, loesses and braided river gravel deposits (Chapter 4). The conclusion that can be drawn is that fire seems to have become a major part of the Grevena environment only after about 15,000 cal yrs BP. Williams (2003) indicates fire was the first great force used by man and that it was manipulated to greatly modify the environment. Fire helped clear land and promoted and maintained the growth of favourable plants (grassland). Prior to the development of agriculture, fire would have been a key tool for hunting and attracting game (Mellars 1976; Williams 2003). It is reasonable to conclude that the late Palaeolithic population in Grevena also used fire as indicated by sites C6, C12, C13 and C19. Fire in the Grevena landscape would ensure open grasslands providing greater mobility and more productive, predictable and safer hunting. Fire-stick farming was widely used by the Australian aboriginal to attract game, encourage desirable species and maintain the open woodland (Hayden 1979; Flannery 1994). Fire in the Leipsokouki catchment may well have provided a major landscape destabilising force. Climate changes prior to 15 cal kyr BP do not appear to have resulted in a major alluvial valley filling. However any evidence of earlier alluvial deposition may have been stripped away by subsequent erosion. Sites such as C7, C20, P38, P60 and P81 indicate that moderately well developed soils occurred in the mid to upper slopes of the Leipsokouki
landscape. Such soils exhibit a range of features such as reddish or very dark soil colours in the B2 horizon, strongly developed soil structure and clayey B2 (Bt) horizons. They also have moderately developed pedogenic carbonate nodules in growth positions. Doyle (1990) calculated soil development indices on many profiles and soil horizons in the Leipsokouki valley to demonstrate this using a modified system described by Harden (1982).

Wild fires due to lightning do not appear likely in Greece as heavy rainfall generally accompany electrical storms. Also whilst living in the Pindos Mountains the author observed numerous pine trees with their tops snapped off. Locals indicated this was due to lightning. Despite the numerous lightning scarred trees none appear to have been set alight despite their resinous nature. Observations in Cyprus reported by Thirgood (1981) suggest natural causes of fire have played a minor role in the tragic fire history on the island.

Major climate fluctuations occurred in the northern hemisphere during the late glacial between 15 - 10 cal kyr BP (Mithen 2003). If these events extended to Greece, and data from Willis (1992) that show an increase in oak at about 13-12 cal kyr BP indicate they may have, then burning to try and reduce any expansion of woodland may have occurred as suggested by sites C6, C9, C12, C13 and C19. These soils underlie the Syndendron alluvium and have been dated to ca. 11 – 14.8 kyr in the Leipsokouki valley. They all contain much fragmentary charcoal in the buried soils. These charcoal ridden soils can often be traced up the valley slopes indicating significant landscape-wide fires were occurring after 15 cal kyr BP.

Stream incision and gully development in the Leipsokouki

Stream valley incision occurs due to increased run-off and stream power; this may be a result of denudement by fire, drought or human clearing, or by an increase in the precipitation. More run-off leads to an increase in stream power and erosion rate (Schumm 1977; Schumm 1991; Goudie 1995). The Leipsokouki has undergone phases of such incision and appears to be incising at present as the stream rests on bedrock throughout its course.
As incision occurs, land sliding commonly increases due to over steepening of side-slopes and gullies may also develop. Generally an increase in sediment supply will occur, due to soil erosion, land sliding and fretting of weaker lithologies. The increase in sediment may lead to local oversupply of sediment and hence valley aggradation (Goudie 1995), particularly where the valley widens and gradients decrease. Such a scenario may have occurred near Tsifliki, at sites C1, C20 and P41, in the upper catchment where a large volume of Syndendron alluvium was deposited in the valley floor. This alluvium was deposited following landscape instability associated with fires and climate change after 12.3 cal kyr BP during 11 - 11.8 cal kyr BP and before 9.9 cal kyr BP as shown by sites C11, C12 and C13. This has resulted in the confinement of the Leipsokouki stream against the true right-hand side of the valley. The impact of this was to undercut the valley side slope and eventually induce land sliding. The landslides resulted in whole pieces of soil moving as intact blocks down the valley side in a matrix of debris flow materials (see Plates 7.1 – 7.2).

If stream power and run-off rates are sufficiently high then sediment will be removed from the local catchment, and incision and gully development will continue unabated until revegetation or slope stabilisation occurs (Goudie 1995). In the Leipsokouki the stabilisation of the Syndendron alluvium did occur in most of the valley and stable soils developed after about 9.9 cal kyr BP at C12 and 9.4 cal kyr BP at P37. Some alluvial deposition may have continued after 9.4 cal kyr BP in the lower catchment as indicated by P37 where the dated paleosol is buried by fine textured bedded alluvium (Plate 5.24). This younger deposit has been called the Syndendron B alluvium.

The development of gullies in the Leipsokouki catchment appears to have become an important process after approximately 4.2 cal kyr BP and particularly after 3.1 cal kyr BP. Prior to this time sediment transport had been largely through soil creep, slope wash and occasional debris flow deposits. No significant gravelly alluvial deposits appear in the valley prior to 4.2 cal kyr BP. However after this time water-worn (rounded) gravel beds appear in the alluvial strata (see sites C14, C2, C3, and C4). These are inter-bedded with finer alluvium and soil colluvium and are followed by soil profile development during a brief stable period. The gravels suggest gully incision was able to supply coarse sediment derived from some of the harder sandstone beds within the Tertiary sediments that form the basement rocks in the mid and upper catchment.
Radiocarbon dated alluvial and hill slope deposits in Leipsokouki Valley

Figure 8.1  Calibrated radiocarbon dates for alluvial, colluvial, debris flow and soil deposits in the Leipsokouki catchment with 95% confidence error bars.
The modern landscape is dominated by active gullies. These gullies appear to be migrating by head-ward incision and fretting on the gully sides. The rate of gully expansion and sediment generation appears to be in balance with the rate of sediment removal from the catchment, as only a thin (1 m) slug of modern floodplain gravelly alluvium occurs on the valley floor.

In some parts of the valley the modern gullies can be seen cutting into slopes that have a convex lateral form (Plate 8.1 and Figure 8.2). The cutting of gullies into convex, water shedding, slope components is unlikely, unless these locations were in the past preferred run-off pathways. As interfluves on the valley side would naturally be droughtier with shallower soils, they are more likely to form field boundaries in a dryland agricultural system. Field boundaries would also act as natural stock routes and become areas of soil compaction and possibly become overgrazed. Such use would make them susceptible to accelerated run-off and gullying. Doyle (1990) has shown how compacted road surfaces and stock routes can control the orientation pattern of run-off and the development of gullies in the Leipsokouki. This can be so pronounced as to cause the natural run-off from the slope above a gully head to be diverted along the contour and into an adjacent gully (Doyle 1990). The run-off was seen to flow along the contour in the rut formed by the hooves of sheep and goats as they migrate laterally across the slopes (Plate 8.2 and Figure 8.2).

In summary gullying is a key landscape process in the Leipsokouki valley. The dating of alluvial sections containing gravelly alluvium indicates gullying probably commenced after about 4.2 cal kyr BP and has remained intermittently active ever since. The only factor that has changed has been the rate of sediment generation (gullying) and that stored within or transported out of the catchment. In the modern setting thin slugs of gravel (<1 m thick) are part of the modern flood plain which suggests stream power is capable of removing the fine sediments and probably a proportion of the gravelly sediment from the valley. In general not much gravel is generated in the valley as the mudstone and shale facies tend to fret and rapidly break-down to grit, silt and sand. The sandstone facies, which are more common in the upper catchment, appear far more capable of forming gravel sized sediment.
Valley filling, fan and terrace formation

If stream power and run-off are incapable of removing the sediment generated then local valley filling will occur. Local fans and alluvial terraces will be deposited in gully bottoms and the local valley floors (Schumm 1991; Goudie 1995). The sediment deposited will depend on the flow regime and particle size of sediment being transported. If coarse gravelly sediment is supplied and stream power is capable of only localised transport then gravelly channel deposits will be a feature of the sediments inter-bedded with finer sediments typical of over-bank deposits and splay deposits. However, if it is largely fine-textured sediment that is supplied, transport and bedded finer alluvial deposits will be the result (Goudie 1995).

At site C13 the presence of ferruginous coatings on wood fragments located in a pit dug into the slope suggest humans were active at that location and may well have played a role in the firing of this and surrounding slopes. Fire is one of the longest lived technologies and the impacts it has on the landscape include; removal of the vegetation cover, exposure of the soil and damage to the soil structure, all of which typically lead to an order of magnitude increase in the erosion rate (Goudie 1995). Mooney and Parsons (1973) have demonstrated dramatic increases in soil erosion in the Chaparral scrub of Arizona following fire. They indicate the rates of erosion increased from 0.43 to over 500 - 1500 t/ha/yr in Mediterranean environments following fire. At C13 slope wash derived from erosion of the upper slopes has buried the lower slopes with 2 m of fine sandy and silty bedded sediment. While site C19 bedded slope wash buries a 14.4 cal kyr BP soil profile with 9 m of fine textured sediment. The Syndendron alluvium is in some parts of the valley more than 11 m thick and indicates a dramatic oversupply of fine textured sediment to the valley floor. This resulted in sediment choking the stream and rapidly filling the valley. This suggests an environment of high sediment supply and a stream (choked with sediment) that was only capable of transporting sediment locally within the valley. The Syndendron alluvium forms its largest deposits where one or more large tributaries meet and the valley widens e.g. at Tsifiiki and below Paleokastro.

Mid and late Holocene alluvium indicates a system now deriving more gravelly material which forms thin beds (<2 m) that are capped by silty and fine sandy sediment prior to further gravel beds and then more fine alluvium. The sedimentary
Plate 8.1  Note gully on formed (dashed line) on the convex lateral component of the slope. This suggests gully initiation occurred due to control of run-off along this axis – perhaps due to the position of a field boundary which became a pathway for sheep and goats.

Figure 8.2  Some gullies have formed on the convex components of the valley side (marked above). This indicates gully initiation may have more to do with field boundaries, stock movement and localized soil compaction than simply land contour. Travel along spurs would also provide good vantage of predators.
Plate 8.2 Sheep and goats tracks can control the direction of run-off flow. Image above shows run-off being directed across the contour taking it from the head of one gully and into the adjacent gully. The compaction associated with the stock tracks appear to reduce infiltration and thus increase the volume of overland flow.

Plate 8.3 Calcareous rhizo-tubule developed in a calcareous sand dune at Croppies Point in NE Tasmania (Doyle 1998). The inter carbonate was radiocarbon dated at 2,810 ± 50 years BP (calibrated Wk6921). The feature demonstrates just how rapidly carbonate can accumulate give an adequate supply of calcium, in this case coarse sand-sized shell fragments, and a mechanism for enhanced precipitation, in this case soil drying associated with root transpiration.
Figure 8.3 Plot of the soil, alluvial and mass movement deposits against the number of archaeological sites in the Leipsokouki Catchment (note radiocarbon dates are calibrated and are shown with 95% confidence level ranges).

Figure 8.4 Plot of the soil, alluvial and mass movement deposit and the number of sites in a given period as a ratio of the length of the period (i.e., an attempt to assess population pressure) in the Leipsokouki catchment (note radiocarbon dates are calibrated and are shown with 95% confidence ranges).
sequences in each mid to late Holocene alluvial section vary greatly as does the height or thickness of the sections, suggesting activity in local gullies and side valleys is of greater significance than the activity of the main stream. The deposits on the valley sides indicate sediment was supplied by slope wash, valley transport and debris flows (themselves indicating wet soil conditions).

After the study of approximately 1500 catchments around the world Wilson (1973) indicates it is very difficult to select a single variable that may be used to explain the variations in sediment yield. However, if one were to be selected it would be land use rather than climate. The arrival of humans in the Grevena region in the Upper Palaeolithic would have begun such land use changes. One of the key factors that may have caused rapid landscape change, despite low populations of humans, is that of fire. In the Leipsokouki the sudden presence of charcoal in the soil profiles, subsequently buried by slope wash, is a strong indication of the impact of landscape change e.g., sites C6, C9, C12, C13 and C19.

Mass movement in the Leipsokouki
Debris flows are an important type of deposit, particularly in the upper Leipsokouki valley (sites C1, C11, and C6). Debris flows have been likened to wet concrete with rates of movement in the order of 0.5-20 m/s. They are composed of granular solids, water and air and are intermediate between landslides and water flows (Goudie 1995). Thus they indicate saturated soil conditions. They may carry material up to several metres in diameter. They originate when poorly sorted rock and soil debris are mobilised on a hill slope due to the addition of water (precipitation, springs, and thaw). They may cause considerable erosion in their tracks. Debris flows are seen as playing a major formative role on alluvial fans with accretion that can vary from 0.15 – 1.0 m/yr (Goudie 1995). In the Leipsokouki at sites C1, C6 and C11 they are clearly providing sediment for subsequent alluvial aggradation.

Soil mineralogy has a role to play in mass movement processes in the Leipsokouki catchment. Many of the soils are dominated by smectite, serpentine and in places some talc occurs. A few soils also have the soapy, magnesium-rich clay minerals palygorskite and sepiolite. These reactive clay minerals have a greasy or waxy lustre and soapy feel (Read 1947; Moore and Reynolds 1989). In fact, sepiolite was used as
a soap substitute in North Africa (Read 1947). Smectite is an expanding clay mineral due to its low inter-layer charge. Borchardt (1977) has shown the importance of expanding clay minerals in explaining land sliding along the Coast Ranges of California as compared to kaolinite and other non-expanding minerals. Goudie (1995) indicates that loss of forest cover commonly leads to widespread surface stripping and in other instances to erosion by mass movement e.g. mud flows, landslides and debris avalanches. Some of the mid-early Holocene debris flows (C1, P41) in the Leipsokouki catchment have pieces of soil profile with many coarse roots, and parts of the whole soil profile appear to have become entrained in a debris landslide (Plate 7.2 and 7.5). The coarse tree roots would suggest a forest cover existed at the time of the landslide. The local slopes are steep (20-30%) and the soils were at that time friable, moderately deep, brown silty clay loams. The debris flows at site C1 occurred as at least two events, separated by thin, charcoal rich soils. This suggests they may be linked to periods of high rainfall and fire in the Middle Neolithic period.

Many of the younger slope deposits are colluvial in origin, derived from both bedrock and calcareous subsoil and transported by gravity assisted by soil moisture changes. The colluvia younger than about 2,500 years are greyish in colour (buff), sometimes stony and always calcareous (C16, C12, C2, P36, P47 and P59). They generally lack the friable strongly developed pedality with interlocking aggregation that is exhibited by the dark coloured, non-or slightly calcareous, soil colluvium greater than 2,300 years in age. The younger colluvia also commonly exhibit stratification with some layers being more compacted and massive. Many of the colluvia lack distinct soil horizonation, instead being stratified, indicating they are pedogenic colluvium rather than a weathering soil profile – the only in situ pedological features being the leaching of some calcium carbonate to the lower parts of the deposit and the accumulation of organic matter at the surface. Neither of these processes requires significant time. The leaching of carbonate can be quite rapid as thick (20 mm) calcareous rhizo-concretions can develop reasonable quickly as shown by Doyle (1998) in sand dunes at Croppies Point in Tasmania (Plate 8.3). Sections C16, C17, C11, C12 and P47 show that sequences of soil-like colluvia, overlying one another, are a common occurrence in the Leipsokouki valley. Each soil-colluvial layer is a distinct and separable soil deposit rather than pedogenic horizon or soil profile. Thus care must be
taken in determining the degree of development of these apparent “soil profiles” as used by Harden (1982). This is because soil materials may become over-thickened, mixed, and generate composite soil profiles. In addition the degree of pedogenic development cannot be taken as an indication of the minimum age of the landform below as most of the pedogenic features (colour, structure, texture, organic matter) may be inherited from the source material, commonly an adjoining slope.

Soil creep and likely mechanisms in the Leipsokouki
Soil creep rates vary from 0.5 to 3 mm/yr and depend on soil texture, soil water content, vegetation cover and slope angle and shape (Yang and Saunders 1986). Factors that increase the rate of soil creep include; steeper slope angles, wetter sites, higher clay content, absence of tree cover and concave slope form. Tree cover has a large impact on reducing soil creep due to soil binding, soil drying and lower diurnal soil temperature variations (Yang and Saunders 1986). Thus loss of tree cover may impact as a trigger to cause periods of soil creep in the Leipsokouki valley. This is because most of the soil materials have reactive minerals and silty clay textures. A marked relative relief with an abundance of moderate to very steep slopes also aids soil creep from slopes to benches and alluvial surfaces in the valley bottom. Soil creep appears to accelerate starting in the early Holocene (C9, C12 and C17). However the soils older than about 14 kyr BP in the lower landscape positions are colluvial but lack the dark-coloured vertic nature of the 10 - 2.5 kyr BP soil-like colluvia (see Plate 5.14).

If stream valley aggradation pauses along with the associate slope wash and mass movement, soil formation may begin and slower landscape processes will begin to dominate. More stable conditions allow for soil formation and soil creep processes. Soil creep can produce a soil-like colluvial mantle on the previously aggrading or eroding landscape components. For example depressions, once active gullies and alluvial deposits in the landscape may become sites for accumulation of soil colluvium. If depressions and lower slopes become mantled with soil-like colluvium this indicates a lack of water power and run-off which are required for incision and erosion. Examples of filling of lower slopes and paleo-channels filled or buried by soil creep include sites C9, C11, C12, C17, P11, P58 and P77. The reason for the soil movement without incision is because the processes are slower and gentler and there
is no aggressive run-off and associated incision; it is in fact a process of stabilisation and soil creep. Creep is probably an important process due to the silty clay textures of the soils. Such textures will adsorb large amounts of soil moisture and the clays are dominantly reactive i.e., smectite. The soils are also well-aggregated allowing rapid water infiltration. Once the soil mantle thickens, the greater volume of soil and thus higher moisture storage capacity probably accelerates the process (Yang and Saunders 1986). Soil creep became an important process in the Holocene; probably due to the increase in soil moisture associated with the climate change (see Figures 2.12 and 8.2) (Bottema 1975; Wijmstra et al. 1990; Willis 1992b; Roberts and Wright 1993; Willis 1994). Later tree clearance on slopes with such reactive soils would enable accelerated creep and lead to the over-thickening and concentration of soil colluvium in depressions and lower slope positions. The process is sufficiently widespread across the Nomos of Grevena to be considered a major geomorphic process in the Holocene (Savina 1989).

**Post 15 kyr landforms and deposits in the Leipsokouki**

The key types of sedimentary deposit from this period in the Leipsokouki are those from moving water processes and those from mass movement process (Ruhe 1975). The water processes include gravelly channel deposits, sandy and silty overbank or splay deposits and slope wash. The deposits from slope processes include debris flows (rapid, wet, mixing), soil creep (slow gravitation movement associated with wetting and drying) and soil colluvium (movement under gravity assisted by soil moisture changes and other soil disturbances e.g. bioturbation, heat changes).

*Syndendron alluvium (A and B)*

A key characteristic of the Syndendron alluvium is its light grey colour and largely fine texture. The alluvium is composed in the most part of inter-bedded well-sorted sands and silt layers of 5-10 cm thickness (sites C6, C17 and P37). The alluvium appears as a fan deposit where gullies and tributaries open out onto the valley floor. The major part of the alluvium, Syndendron A, is finely bedded and has been dated at between 14.2 – 9.9 cal kyr BP in the upper and mid catchment. However, in the lower catchment deposition may have recommenced after 9.4 cal kyr BP as approximately 1 m fine alluvium caps a distinct paleosol at P37 (Plate 5.24). This is called the Syndendron B alluvium and is dated to 9.4 – 8.0 kyr BP (see Table 8.1).
Table 8.1 Alluvial units in the Leipsokouki valley

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>14C years BP</th>
<th>Calibrated yrs BP</th>
<th>Archaeological artefacts (Wilkie and Savina 1992)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leipsokouki alluvium</strong></td>
<td>C18, Capped by calc. coll.</td>
<td>Modern (C18)</td>
<td>&gt;140 + 130</td>
<td>Probably Hellenistic, Roman, Ottoman &amp; late Early Bronze</td>
</tr>
<tr>
<td></td>
<td>P29, P31, P33, P50, P55</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is a very recent channel and over-bank deposit with young and incipient soils (entisols). The alluvium forms a 1 - 3 m thick deposit on the valley floor comprised of a gravelly lower part (channel type) and a silt – fine sandy upper part (over-bank type). The gravelly channel deposits contain sherds from Bronze Age to the Ottoman period indicating the alluvium is <0.5 kyr BP. The soils which form in the over-bank deposits have only weak – moderately developed topsols and lack "colour" B2 or cambic horizons. The alluvium may be capped by recent calcareous colluvium if deposited close to valley slopes, e.g., C18 as dated above.

<table>
<thead>
<tr>
<th><strong>Sirini alluvium (A, B &amp; C)</strong></th>
<th>Modern incipient soil profile not dated, often formed from colluvium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sirini C, 2.1 – 1.7 kyr BP</td>
<td>C16a, Greyish calc. colluvium</td>
</tr>
<tr>
<td></td>
<td>1,804 + 47</td>
</tr>
<tr>
<td></td>
<td>1,735 + 135</td>
</tr>
<tr>
<td>C4a, Upper colluvial soil</td>
<td>2,047 + 56</td>
</tr>
<tr>
<td></td>
<td>2,090 + 60</td>
</tr>
<tr>
<td>Sirini B, 3.1 – 2.1 kyr BP</td>
<td>C4b, Sirini B alluvium</td>
</tr>
<tr>
<td></td>
<td>2,946 + 146</td>
</tr>
<tr>
<td></td>
<td>3,100 + 350</td>
</tr>
<tr>
<td>P52, Sirini B alluvium</td>
<td>2,330 + 70</td>
</tr>
<tr>
<td></td>
<td>2,450 + 300</td>
</tr>
<tr>
<td>C3a, Sirini B alluvium</td>
<td>2,785 + 128</td>
</tr>
<tr>
<td></td>
<td>3,025 + 325</td>
</tr>
<tr>
<td>C16b, Coll. soil on Sirini B</td>
<td>2,302 + 47</td>
</tr>
<tr>
<td></td>
<td>2,295 + 145</td>
</tr>
<tr>
<td>C14, Sirini A alluvium</td>
<td>3,797 + 165</td>
</tr>
<tr>
<td></td>
<td>4,150 + 500</td>
</tr>
</tbody>
</table>

This alluvial fill is quite distinct in the valley and forms a 4-9 m thick alluvial fans, typically where side-streams meet the main valley. They are composed of alternating channel and over-bank deposits with one key soil developing ca. 4 – 3.1 kyr BP. This buried soil separates the Sirini alluvium into Sirini A ca. 4.2 - 3.1 cal kyr BP and the Sirini B ca. 3.1 – 2.1 kyr BP. Clearly this alluvia began deposition in the Early-Middle Bronze Age and then stabilised allowing a brief period of soil formation before recommencing alluvial deposition until about 2.1 kyr BP. A later phase of alluviation occurs at C16 with 1.4 m of deposition between 2.1 – 1.7 kyr BP (Sirini C).

<table>
<thead>
<tr>
<th><strong>Amygdalies alluvium the colluvial capping</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium 5.9 – 4.7 kyr BP</td>
<td></td>
</tr>
<tr>
<td>C8d, Upper gravelly colluvium</td>
<td>3,967 + 185</td>
</tr>
<tr>
<td></td>
<td>4,375 + 525</td>
</tr>
<tr>
<td>C8c, 1st buried alluvial soil</td>
<td>4,134 + 47</td>
</tr>
<tr>
<td></td>
<td>4,685 + 165</td>
</tr>
<tr>
<td>C8b, 2nd buried alluvial soil</td>
<td>4,707 + 159</td>
</tr>
<tr>
<td></td>
<td>5,300 + 450</td>
</tr>
<tr>
<td>C8a, Basal alluvium</td>
<td>5,141 + 184</td>
</tr>
<tr>
<td></td>
<td>5,875 + 425</td>
</tr>
</tbody>
</table>

This alluvial and colluvial section is described at site C8 in the Amygdalioitikos tributary. It is very tightly constrained and represents a series of small scale alluvial aggradation events which are followed by short (500 years) periods of soil formation before further alluvial deposition. The alluvial events are associated with hill slope erosion as shown by lateral facies changes from alluvium to colluvium with increasing proximity to the adjacent slopes, particularly after 5.3 kyr BP. The site was buried by over 2 m of gravelly colluvium after 4.4 kyr BP. The main alluvial deposit is 5.9 – 4.7 cal kyr BP.
Table 8.2 Slope deposits in the Leipsokouki valley

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>14C years BP</th>
<th>Calibrated yrs BP</th>
<th>Archaeological artefacts (Wilkie and Savina 1992)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very recent calc. coll.</td>
<td>P71, P4, P23, C12, C18</td>
<td>Modern</td>
<td>140 + 130</td>
<td>Ottoman, Turkish glass, roof tiles, Post Byzantine</td>
</tr>
<tr>
<td>Recent dark greyish brown and brown colluvial soils</td>
<td>C2, Dark grey soil colluvium</td>
<td>312 + 38</td>
<td>380 + 90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P40, Thin buried colluvial soil</td>
<td>750 + 70</td>
<td>675 + 125</td>
<td></td>
</tr>
</tbody>
</table>

The Syndendron alluvium forms a substantial silty to fine sandy deposit in the Leipsokouki valley which varies from ca. 2 m to more than 11 m thick. It is separated by a 9.4 kyr BP paleosol into two parts - Syndendron A and B. The Syndendron A is composed of fine sands with common grit layers at its base and well-stratified silty to fine sandy alluvium in the upper part. The upper part of the Syndendron A alluvium is typically capped by a dark buried silty clay loam colluvial soil dated to 8.1 - 9.9 kyr BP. At some sites e.g., P37 about 1 m of fine textured alluvium caps a 9.4 kyr BP paleosol – this overlying alluvium is termed Syndendron B. At site C17 0.2 m of fine alluvium caps the paleosol formed above the Syndendron A – this is also termed Syndendron B. Very dark brown pedogenic colluvial materials cap most Syndendron alluvial sections. These dark pedogenic colluvia appear to have been deposited in at least three and commonly four phases each identified by separate soil morphological characteristics at ca. 9.9 - 9.4, 8.0 - 7.5, 5.3 - 4.3 and 3.9 - 2.7 kyr BP with lighter coloured, more recent, calcareous colluvium at the surface at ca. 2.2 – 1.4 and 0.7 – 0.4 kyr BP.

This unit is characterised by its very pale grey colour and highly calcareous nature. The deposits are very recent and may relate to current active erosion but certainly in some part to the period of modern mechanised agricultural and roading. These materials typically lack the development of a distinct topsoil and so are extremely young.

These recent, and often buried soil colluvia commonly show some leaching of calcium carbonate and the weak development of an organic topsoil as indicated by darker colour and structural development. They lack a B2 horizon and cap the Sirini and Leipsokouki alluvium at some sites indicating they are Byzantine or younger in age.
### Thick dark greyish, partly leached calcareous colluvia

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>14C years BP</th>
<th>Calibrated yrs BP</th>
<th>Archaeological artefacts (Wilkie and Savina 1992)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P36</td>
<td>Greyish calcareous coll.</td>
<td>1,410 + 50</td>
<td>1,390 + 130</td>
<td>Roman &amp; Byzantine sherds in upper 1 m, Hellenistic below 1 m</td>
</tr>
<tr>
<td>C16a</td>
<td>Greyish calcareous coll.</td>
<td>1,804 + 47</td>
<td>1,735 + 135</td>
<td></td>
</tr>
<tr>
<td>P47</td>
<td>Greyish calcareous coll.</td>
<td>2,190 + 70</td>
<td>2,175 + 175</td>
<td></td>
</tr>
<tr>
<td>C16b</td>
<td>Dk. soil coll. on Sirini all.</td>
<td>2,302 + 47</td>
<td>2,295 + 145</td>
<td></td>
</tr>
</tbody>
</table>

Thick (>1.5 m) stratified, calcareous colluvia occur in many parts of the mid catchment in fossil gullies. They lack soil profile differentiation other than an inherited slight darkening of the topsoil due to organic matter accumulation and the leaching of some of the calcium carbonate from the upper profile.

### Very dark brown, non-calcareous, pedogenic colluvia

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>14C years BP</th>
<th>Calibrated yrs BP</th>
<th>Archaeological artefacts (Wilkie and Savina 1992)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P11</td>
<td>Dk colluvium</td>
<td>2,650 + 200</td>
<td>2,750 + 600</td>
<td>Early Iron Age</td>
</tr>
<tr>
<td>P58</td>
<td>Dk. colluvium</td>
<td>Not dated</td>
<td>&lt; 3.9 – 2.7 kyr</td>
<td>Iron Age or Early-Middle Bronze Age</td>
</tr>
<tr>
<td>P77</td>
<td>Dk colluvium</td>
<td>Not dated</td>
<td>&lt; 3.9 kyr</td>
<td>All Middle Bronze Age (single period)</td>
</tr>
<tr>
<td>C8e-d, Stony reddish coll.</td>
<td></td>
<td>&lt;4.7 – &lt;4.4 kyr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C11c</td>
<td>Dk colluvium</td>
<td>4,429 + 138</td>
<td>5,050 + 450</td>
<td></td>
</tr>
<tr>
<td>P59</td>
<td>Dk colluvium</td>
<td>4,400 + 60</td>
<td>5,065 + 225</td>
<td></td>
</tr>
<tr>
<td>C12c</td>
<td>Dk colluvium</td>
<td>6,627 + 142</td>
<td>7,500 + 250</td>
<td></td>
</tr>
<tr>
<td>C17c</td>
<td>Dk colluvium</td>
<td>7,218 + 47</td>
<td>8,050 + 110</td>
<td></td>
</tr>
<tr>
<td>C9c</td>
<td>Dk. colluvium</td>
<td>7,303 + 57</td>
<td>8,085 + 115</td>
<td></td>
</tr>
<tr>
<td>P37</td>
<td>Dk paleosol on Synd. A</td>
<td>8,380 + 170</td>
<td>9,350 + 600</td>
<td>Grinding stone (note alluvium above the is called Syndendron B)</td>
</tr>
<tr>
<td>C12b</td>
<td>Dk. coll on Synd. B.</td>
<td>8,816 + 58</td>
<td>9,900 + 300</td>
<td></td>
</tr>
</tbody>
</table>

These materials are typically pedogenic in nature – they are however over-thickened gully or depression accumulations of soil like colluvium. They lack a “colour” B2 horizons but would meet the requirement of a “structure” B2. However, the deposits are clearly the redeposited remains of previous soil materials derived from up slope e.g., dark vertisols and mollisols leading to inherited pedogenic character. Overall the sections lack clear soil horizon differentiation. However, carbonate has been leached from upper 0.5m of most dark pedogenic colluvia, with distinct increases in carbonate in the base of the gully fills. The materials must have moved by creep and colluvial processes rather than by slope wash so as to preserve the pedogenic characteristics.

### Debris flow deposits

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>14C years BP</th>
<th>Calibrated yrs BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Debris flow with soil pieces</td>
<td>5,710 + 142</td>
<td>6,550 + 350</td>
</tr>
<tr>
<td>C11</td>
<td>Calcareous stony debris</td>
<td>6,605 + 99</td>
<td>7,490 + 180</td>
</tr>
<tr>
<td>P76</td>
<td>Stony compact debris</td>
<td>8,816 + 58</td>
<td>9,900 + 300</td>
</tr>
</tbody>
</table>

These materials are characterised by fine matrix with common, angular gravels, stones and sometimes boulders. The materials are commonly very compact suggesting they set hard from a saturated state. At site C1 the lower debris flow deposit is capped by a stony debris with a fine matrix debris which contain large (1x3 m) pieces of intact soil profile indicating a semi-fluid slide caused the deposit.
The Syndendron A alluvium is fine-textured (silts and fine sands) which indicates the source of the sediment is likely to be the fine soil materials of the mid and upper slopes, as the soils in the lower slopes and valley floor at that time appear to be relatively thin and are generally buried by the alluvium and associated slope wash deposits and at C6 a debris flow deposit. This suggests quite rapid accumulation of the alluvium. The upper slopes and ridges which have loess-paleosol cover beds could provide ample fine-textured, calcareous sediment. The general lack of gravel, stone and boulder beds can be taken to indicate the erosion, which generated the sediment, was not deep-seated enough to cause the significant gullying required to supply coarser sediment (gravel and rock). Thus it appears the catchment was not gullied at the time of this erosion and deposition event. Sites C6, C9, C19 and C13 where intact soil profiles underlie the alluvium support this conclusion. The sediment must have been sourced from the paleosols and fine textured sediments (loess) that mantled the upper slopes and catchment divide. If this erosion and associated deposition was associated with early human fire-induced disturbance of the catchment then it would suggest the focus of activity was as it is today, that is on the mid and upper slopes of the mid and upper catchment e.g., the villages of Syndendron, Amygdalies, Rodia, and Mega Sirini.

Several soils have developed on the Syndendron A alluvium and radiocarbon dating indicates soil development began soon after 9.9 cal kyr BP (C12). Soil profiles only develop in the upper part of the alluvium or on it. Beneath the alluvium several soils have been dated. These buried soils range from 11.0 to 14.7 cal kyr BP and suggest that as the alluvium aggraded it buried soils higher in the valley i.e., the 11.0 kyr date at C12. Some of the soils buried by the alluvium are truncated (C12) and all contain much charcoal (C6, C9, C11 and C13). This indicates fire was associated with the erosion and deposition.

The processes leading to the formation of the Syndendron alluvium include slope wash, which Yang and Saunders (1986) describe as having huge variation in Mediterranean environments. They indicate that rates can vary over two orders of magnitude i.e. 2-200 mm/1000 year and surface wash is the predominant denudation process in semi-arid climates. Certainly slope wash of fine-textured sediment was a process likely to provide the large volumes of fine textured sediment which is typical
of the Syndendron alluvium as shown by sites C13 and C19. This sediment then rapidly accumulated in the valley floor forming up to 11 m in thickness e.g., sites C17, P37, and C6. The sedimentation rates at a range of the Syndendron alluvial sites have been calculated in and are presented in Table 5.26. The mean is 1.4 mm/yr and is likely to be an under estimate due to periods of erosion and over estimates of the age of the base of the alluvium (based on soils it buries). A reasonable maximum rate of sedimentation of 2.7 mm/yr was calculated for P37. The real mean sedimentation rate is likely to be slightly less than this value.

A rate of approximately 2.5 mm/yr seems a reasonable assumption for the Syndendron alluvium. This rate is in the moderate to high range and indicates moderately erosive environments in the upper and mid catchments between 14,750 and 10,955 cal yrs BP. However an estimation of the erosion rate on the valley slopes is not possible as the volume of sediment transported out of the catchment is not known. Chester (1991) has shown high sedimentation rates in the last 500 years for Kellia fen in the mid catchment (3.4 mm/yr). However Willis (1992c) indicates sedimentation rates at less than 0.6 mm/yr prior to 4,500 cal yr BP at Rezina Marsh. These increase dramatically to 4.6 mm/yr in the Early Bronze Age and decline to 2.1 mm/yr in the Middle and Late Bronze Ages before dropping further in the Dark Ages (1.2 mm/yr). The implication being that the higher sedimentation rates are associated with human disturbance and particularly fire (Chester 1991).

The Syndendron A alluvium may indicate the arrival of humans and accelerated burning of the catchment although climate change and natural fires cannot be ruled out. Bailey (1997) indicates steppe conditions may have been maintained by the use of fire during the upper Palaeolithic in Epirus. Upper Palaeolithic axe heads have been found in the Grevena region indicating humans were present, however their impact on the environment has generally been considered to be minor (Wilkie and Savina 1997). Whatever the cause, hill slope destabilisation was catastrophic, with debris flows and slope wash filling the valley to a depth of 15-20 m with sediment.

Post Syndendron soil creep and colluvial deposits
The colluvial soils that buries the Syndendron alluvium (A and B) have been dated throughout the catchment at approximately 8,000, 8,100, 9,350 and 9,900 cal yr BP at
sites C17, C9, P37 and C12 respectively. The soil colluvium has mostly moved to the sites by soil creep processes from adjoining slopes. At C17 the orientation of prismatic peds, which are tilted down slope, in one of the upper colluvial layers, indicates the active nature of the creep process. Figure 8.2 indicates that soil creep has occurred throughout the early to late Holocene in the Leipsokouki. Other forms of soil colluvial transport dominate after about 2.3 kyr BP. The pre-Holocene colluvial soils at sites C6, C12, C13 and C19 indicate a different type of colluvial transport, perhaps a reflection of the generally drier conditions in the last glaciation (Atkinson et al. 1987; Goudie 1987; Wilson et al. 2000; Mithen 2003). These colluvial soils have olive brown subsoils with angular lithic fragments, orange mottles and thinner dark topsoils. While the colluvial soils of the early to late Holocene are all very dark brown-black, deep, cumulate-type soil profiles, representing the accumulation of dominantly topsoil materials through soil creep (C12, C17, P11, P37 and P77). This suggest a moister climate leading to greater amounts of soil organic matter and more rapid soil creep (Yang and Saunders 1986).

Amygdalies alluvium

Two sites provide evidence of an alluvial deposition in the early-mid Holocene. Site C11 has a localised alluvial deposit related to the supply of sediment by a debris flow deposit. This alluvium is bracketed between 7,490 and 5,050 cal yrs BP (see Table 8.2). While at site C8 alluvium and colluvium deposited in the lower Leipsokouki valley in a tributary stream called the Amygdaliotikos stream demonstrates sedimentary deposition in the period between approximately 5,900 and 4,400 cal yrs BP (see Table 8.1). During this period 1.5 m of fine textured alluvium accumulated. This indicates a moderately low sedimentation rate of 1.2 mm/yr (see Table 6.16). Surrounding hill slopes appear to have contributed some of the sediment but the generally fine texture indicates the sediment was probably sourced from the mid and upper catchment area. In the upper catchment two debris flow deposits at site C1 are separated by a charcoal rich soil layer dated to 6,550 cal yrs BP. This hill slope activity may have helped supply sediment for the valley floor aggradation. At site C8 alluvial deposition ceases after about 4,400 cal yrs BP. The alluvium is buried by over 2 m of gravelly colluvium transport from the adjacent slopes. This colluvium helps to preserve the site from any subsequent stream incision. The preservation in this manner is a clear reminder that other sedimentary evidence may have been
removed from the valley when burial is not able to provide such protection. In other words the record developed here may not be complete.

During the period of alluvial deposit at C8 other colluvial activity was recorded in the valley. At site P59 soil creep led to the deposition of very dark, silty clay soil over the Syndendron alluvium at \textit{ca} 5,065 cal yrs BP (see Table 8.1). This colluvial soil was later buried by several meters of fine textured, calcareous greyish brown colluvium (not dated). While at site C11 several meters of dark brown soil-like colluvium, dated to 5,050 cal yrs BP, buried older colluvium which itself had buried the Syndendron alluvium. This colluvial activity in other parts of the valley hints that the slopes were active at the time of the Amygdalies alluvial deposition. Indeed at the site the colluvial units can be seen to grade laterally into the alluvial deposits. The Amygdalies alluvium dates from the Late Neolithic to Early Bronze Age. While the Early Bronze Age saw a large increase in sites in the Nomos of Grevena in the Leipsokouki valley there are at least five soils that contain Middle Bronze Age sherds (P6, P11, P30, P58, and P7; Doyle 1990). The Early Neolithic was also a period with abundant sites in the Nomos and in this valley. However the onset of the Neolithic was later in northern Greece meaning the timing may indeed relate to heightened human activity in the valley. Alluvial aggradation was noted at both Thessaly (Demitrack 1986) and the Argive Plain (Finke 1988) during the Neolithic period, and in both cases this was related to human activity. No significant climatic fluctuations are indicated for this period from oxygen isotope data but glacial advances did occur prior to 6 kyr BP in both the European Alps and in Scandinavia (see Figures 8.7 and 8.8). Also in the European Alps an advance occurs at about 5.4 - 4.8 cal kyr BP which coincides with the middle part of the Amygdalies alluvial aggradation. However the fact that the first part of the alluvial deposit is correlated with a glacial retreat and the second with an advance raises doubt about any suggestion the climatic changes indicated in the European Alps are associated with the advances is related to alluvial activity.

Site C8 suggests alluvial aggradation from fine sediment sources continued until 4,375 years BP after which hill slope colluvial processes dominated and led to the burial of the site with hill slope colluvium. This sequence of significant alluvial
deposition being followed by colluvial deposition is repeated in both the Sirini and Syndendron deposits.

*Sirini alluvium (A, B and C)*

This alluvial deposition begins after 4,150 cal yr BP with a series of inter-bedded gravel and sandy stream channel type deposits (called Sirini A, see Table 8.1). The gravels are water-worn, imbricated, well sorted and display lateral channel features and grading (Plates 6.7 and 6.8). Small amounts of gravelly alluvium was deposited during the early – middle Bronze Age (C14a) but deposition rapidly accelerated after 3,100 cal yr BP (called Sirini B, see Table 8.1). The water-worn gravels are generally buried with fine-textured alluvial sediments. The alluvial deposition was separated by short periods during which soil development occurred (see sections C14, C2, C4). It appears, from site C14, the Sirini A deposition extended from about \(4,150\) cal yr BP to about 3,500 yr BP, an accelerated rate of deposition, Sirini B, occurs between 3,100 and 2,000 cal years BP. At one site, C16, alluvial deposition may have continued a little later as a soil dated to 1,700 cal yr BP has formed the Sirini alluvium deposited after 2, 295 cal yrs BP (see Plate 6.13).

Site C14 is composed of 5.4 m of alluvium aggraded in two distinct phases. These are separated by a moderately developed mottled buried soil into Sirini A and Sirini B alluvium (see Plates 6.7 and 6.8). The buried alluvial soil probably represents several hundred years of local stability (and stream incision) based on its morphology. In the gravels near the base of the section, Middle Bronze Age and possibly Neolithic pot sherds were found while the finer sediments below the gravels have been radiocarbon dated to 4.15 cal kyr BP (Wilkie and Savina 1992). The Middle Bronze Age sherds found in the lower gravels suggests they are younger than 4000 yrs BP. The gravels are capped by finer alluvium and a mottled soil profile. Lying above the mottled buried soil is post Hellenistic alluvium based on the presence of Hellenistic-Early Roman pot sherds (Wilkie and Savina 1992).

Lower in the catchment below the village of Mega Sirini, soil profile P52 overlies a 9.6 m alluvial terrace consisting of stratified silts and sand with occasional fine gravel layers (refer to Figure 6.3 and Plate 6.8). This alluvium is dated 3 m above its base at 2,450 ± 300 cal yrs BP (Wk1579). This places the majority of the aggradation (~6.5
m) in the Classical to Roman periods. But also indicates significant alluvial deposition prior to 2.5 Ka. This concurs with evidence from sites C4 and C3 which suggest the aggradation of Sirini B alluvium began after 3.1 cal kyr BP. The P52 alluvium contains two buried soil layers although they appear to be colluvial in origin as they contain angular and sub-angular coarse fragments floating in the finer soil matrix. Thus they do not suggest significant periods of landscape stability, rather they indicate colluvial slope processes dominated over alluvial aggradation.

In the upper part of the mid catchment soil profile P18 exposes an alluvial and colluvial deposit of only 2.5 m thickness (Doyle 1990). It consists of a fine grained depositional alluvium containing seven intervening buried soils (refer to Plate 8.4). The lower five buried soils were thought to be fluvial soils formed on the alluvial deposits. However close examination indicates the soils contain angular lithic fragments and thus indicate the soil layers are more likely colluvial in origin. This is supported by the abrupt lower boundary of the soil layers on to the alluvium, indicating they were deposited on a prior surface. Also two of the buried soils merge upslope indicating both their source and cyclic nature of their deposition. All the buried soils are identified by their morphology and chemistry. They have a darker colour (10YR 4/2), a blocky structure, lower pH and lower levels of CaCO₃ than the intervening alluvial and colluvial sediments (Doyle 1990). These soil properties are thought to be due to leaching and possibly brief pedogenesis. However this need not have occurred in situ. Site P18 clearly demonstrates the close link between activity on the slopes and that of the alluvial aggradation. Alluvium is deposited during major floods as fine textured over-bank deposits, while during intervening periods associated with lower stream flow, soil creep and colluvial deposition are the dominant processes. The site demonstrates rapidity of slope processes with this catchment where reacting clay minerals lead to accelerated soil creep.

The examination of a range of Sirini alluvial sites indicates it is in part derived via gully development in the side-valleys. This is indicated by the discontinuity of the deposits down stream, at several sites the bedding dips up the valley, and the location of the deposits are always close to the confluence of gullies and the main valley.
Plate 8.4 The “Seven buried soils” site P18 from Doyle (1990) which shows inter-bedded colluvial soils and alluvium at the base of the section while colluvial soils dominate in the upper part of the section. Note gleyed alluvial sediment at base of section which is probably due to slowly permeable mudstone bedrock beneath the alluvial sediment. A similar gleyed soil occurs in C3.
Commonly the beds are deposited at a dip of between 4-14° (C3, C14, C2, P52), which in some cases results in the alluvium dipping upstream. This is only possible if the deposit is part of a fan derived from a side stream/gully.

The lower part of the Sirini alluvium is interpreted as beginning in the late Early Bronze to Middle Bronze Age based on pot sherds and radiocarbon date of 4.15 cal kyr BP at C14 (termed the Sirini A alluvium). However much of the Sirini alluvial sedimentation occurred after 3.1 cal kyr BP as indicated in C3 and C4 and after 2.45 cal kyr BP as indicated by P52 (Sirini B). The younger part of the Sirini alluvium (Sirini B) commonly contains Classical, Hellenistic or Early Roman pot sherds within the gravel lenses. Aggradation may have began as early as Early-Middle Bronze Age at C14 but this was followed by a soil forming period that must have been several hundred years in duration based on organic matter accumulation, mottling and leaching of calcium carbonates (see Plate 6.7). The main part of the Sirini alluvial aggradation, Sirini B, came after this soil formation, most probably in the Classical to late Roman period, but it may have begun as early as the Iron Age, as shown by C3 and C4. The Iron Age was a major period of occupation in the Grevena and neighbouring regions (Wilkie 1995). This aggradation was not a simple alluvial fill in response to a single period of erosion but rather a staggered progressive accumulation of gravels and silts at times of flooding and sediment discharge. The initial period of aggradation was separated by soil formation at C14 when the stream channel remained stable or began to temporarily re-incise. The main aggradation, Sirini B, continued and created alluvium measuring up to 10 m thick in the mid catchment. Sometime following the final aggradation of the Sirini alluvium (Sirini C from 2.1 – 1.7 kyr BP at c16), re-incision of the alluvium to the bedrock stream base occurred. This happened after 1.7 cal kyr BP as indicated by site C16. During this later period, soil formation and colluvial deposition on the Sirini surface occurred. Some isolated locations, away from slopes, received no colluvium, while others, like C4 and C16, received deposition of colluvium from adjoining slopes.

The alluvial sequences of the Sirini deposit are different in the various parts of the valley. Thickness of the alluvium is a major variable, ranging 2.5 to nearly 10 m. Generally more gravelly alluvium occurs at the base of the Sirini A and Sirini B deposits and finer silty and sandy alluvium above. However some sites have
dominantly finer sediment throughout while others have a mixture of gravels and finer sediment throughout e.g. P52. These factors, thickness and facies variations, highlight the role side-valleys play in supplying sediment. They are clearly very important in the type of sediment generated and in controlling the rate of alluvial deposition. The fact that some alluvial layers can be demonstrated to dip upstream indicates that much of the alluvium is part of small alluvial fans that form where the side-streams meet the wider and flat main valley floor. At this point the stream flow energy level reduces and deposition occurs.

**Contemporary and post Sirini colluvial deposits**

At several sites the Sirini alluvium and associated gullies and depressions have become buried of filled by colluvial deposits of various types (C4, C16, P11 P36, P47, and P77, see Table 8.2). The reactive nature of the clay minerals in the valley (smectite) and the generally silty clay soil textures greatly assist in soil creep as well as shallow land sliding and colluvial slope processes (Borchardt 1977). The alluvial deposition phases must be associated with higher water flow to provide an erosive regime on slopes and adequate sediment supply to the valley floor. Following stabilisation of the erosive and incisive regime the processes of soil creep and colluvial transport on slopes then led to the filling of depressions and foot slopes with creep material from adjacent slopes. Soil creep is probably the main process for the slope deposits described at sites C4, C16, P11, P36, P47, P58, and P77. The early to mid Holocene soil creep deposits have darker hues than the latter colluvial deposits, perhaps indicating greater soil stripping during erosion in the later part of the Sirini event. The Sirini event appears to start at ca 4,150 cal yr BP but then pauses and a dark, mottled, alluvial soil develops on one part of the alluvium, while an adjacent part is buried by colluvium from adjoining slopes (see site C14). However the Sirini alluvial deposition then accelerates after about 3,100 cal yr BP as demonstrated at sites C3, C4 and P52. The early deposition has been identified here as Sirini A and the post 3.1 cal kyr BP component as Sirini B. The Sirini A occurs in the Mid-Late Bronze Age which was an important archaeological period in Grevena while the Sirini B is deposited during another busy archaeological period in Grevena i.e., Iron Age, Classical, Hellenistic and Roman periods (refer to Figures 2.1 – 2.5).
The Sirini alluvium coincides with a series of colluvial deposits on the valley sides dated between 5,000 (C11, P59) and 1,700 cal yr BP (C16). The Sirini alluvium was a staggered event with one distinct soil forming during a pause in the aggradation. All other soil like layers appear to be colluvial in origin i.e., they contain angular and sub-angular coarse fragments in fine soil matrix. Re-incision of this deposit occurred some time after about 1,700 cal yr BP as indicated by site C16 and supported by C4.

Leipsokouki alluvium
The youngest alluvial deposit in the valley is the Leipsokouki alluvium which is likely to be less than about 500 years old. However dating using the radiocarbon method gave a modern age. A date of 380 cal yr BP at site C2 indicates colluvial sediment was being generated from adjacent slopes. This activity may have helped generate sediment to produce alluvium on the valley floor. Other activity on the valley slopes is indicated by site P40 where soil colluvial processes were active after 680 cal yrs BP. Weak soil development on the Leipsokouki alluvium also supports the notion of youthfulness of this deposit. Since the Leipsokouki alluvium was deposited, only thin and very incipient soils have developed on the alluvial sediment. The modern stream has now re-incised back to its bedrock base. The deposit may be either a response to climatic change, the “little ice age”, or to increased human disturbance of the slopes following increased populations that is suggested by the increase in site numbers during the Ottoman period (refer to Figures 2.1 – 2.5).

Greyish brown colluvial materials – younger than 2.3 ka BP
Most colluvial deposits become less “soil-like” and become more calcareous, stonier and more weakly structured after about 2.3 cal kyr BP. This is probably due to the loss of soil-landscape cover that leads to the younger sediments being derived from the BC-horizons and C-horizons as well as the bedrock. Much of the material could easily be derived from gully walls as incision and flow in the gully slows to allow for deposition. Soil profiles P22, P34, P36, P39, P40, P42, and P47 as well as the upper parts of C2, C12 and C16 demonstrate these phenomena.

Soil carbonate dating and soil age
Calcium carbonate distribution can be used as an index of soil development as it is relatively mobile substance but can also form a range of distinct pedogenic
precipitation forms (Birkeland 1999). The author has dated soft calcium carbonate accumulation around tree roots in calcareous sand dunes on the NE coast of Tasmania. These tubes of calcium carbonate, which seem to have grown around roots and have a radius of up to 20 mm are dated to 2,810 ± 50 BP (Wk 6921) years (Doyle 1998). While the rate of carbonate build up is probably extremely high, due to the calcareous nature of the material, its sandy nature and the exclusion of calcium by the active root, it suggests that some precipitation of carbonate of a pedogenic nature can occur reasonably rapidly in some environments. Goudie (1995) discusses leaching of carbonate from sand dunes in England and has reported complete leaching of carbonate in as little as 300 years. Olson (1958) has reported leaching of calcium carbonate to a depth of 2 m in calcareous dunes at Lake Michigan. Thus it would appear if rainfall is sufficient and the soil is permeable leaching of calcium carbonate may occur in a thousand years or so. However the Leipsokouki soil materials are much finer, typically silty clay loams, and also form under a far lower rainfall (<600 mm/yr). This will reduce the rate of leaching. Many examples of partly leached soil profiles, some of which are now buried by more calcareous colluvium, occur in the valley include CDS-Red, C9, C17, P4, P11, P13, P15, P16, P18, P19, P20, P27, P34, P36, P37, P38 and P77 (Doyle 1990). The different parent materials in the valley make interpretation of the carbonate leaching problematic. Colluvium may be derived from leached soil material, calcareous B-horizons or some intermediate material such as the bedrock. Hence dating in this study has tried to rely mainly on the radiocarbon method and archaeological evidence rather than pedological indices as presented in Doyle (1990). The main use of calcium carbonate leaching profiles has been in the separation of different soil materials as shown by Doyle (1990). An abrupt change in the typical carbonate leaching profile is strong evidence of a separate soil layer (Butler 1959; Butler 1967).

The development of large (>30 mm) hard, highly recrystallised carbonate nodules is restricted to the paleosols found within the Plio-Pleistocene sediment. However smaller nodules were present in some of the more strongly developed soils on the valley sides including CDS-Red with 10-20 mm nodules, CDS3 with 5-20 mm nodules and C7 with 10-20 mm nodules. The formation of these nodules which appear in situ indicates the moderate to strong development of some of the modern soil profiles. No dating of these nodules has been undertaken in the Leipsokouki
valley but radiocarbon or Ur-series dating may help pin down the age of some of the older modern soils on the mid and upper slopes.

Role of climate change on soil erosion and alluvial deposition

The question often asked in the Mediterranean environment is whether climatic or human factors are the primary cause of valley aggradation and accelerated hill slope erosion. Other causes may be tectonic activity and vegetational change; however the latter is usually related to either human or climatic impacts. This question has been addressed by a number of authors in various studies throughout the Mediterranean (Judson 1963; Eisma 1964; Judson 1968; Vita-Finzi 1969; Kraft et al. 1977; Eisma 1978; Davidson 1980; Kraft et al. 1980; Thirgood 1981; Wagstaff 1981; Wertime 1983b; Pope et al. 1984; Pope and Van Andel 1984; Demitrack 1986; Van Andel et al. 1986; Finke 1988; Van Andel 1989; Van Andel et al. 1990; Chester and James 1991; Zangger 1992a; Zangger 1992b; Runnels 1995b; Van Andel and Runnels 1995) (see Figure 8.7). It was Vita-Finzi (1969) who argued against an anthropogenic cause for erosion claiming that two distinct valley fills, which he called the "Younger Fill" and the "Older Fill", occurred in most Mediterranean valleys and thus indicated regional climatic control. The climatic control model was strongly supported by Bintliff (1975; 1976). However, the idea of synchronicity of alluvial deposition around the Mediterranean, especially regarding a single younger fill has been questioned by many subsequent studies (Davidson 1980; Pope and Van Andel 1984; Demitrack 1986; Van Andel et al. 1986; Van Andel et al. 1990; Zangger 1992a; Zangger 1992b; Runnels 1995b; Van Andel and Runnels 1995) (see Figure 8.7). If climate is the controlling factor rather than human impacts then periods of moderate climate change, in particular droughty conditions which reduce vegetative cover should correlate with periods of erosion throughout the late glacial and Holocene period (Butzer 1974; Butzer 1982). Indeed periods of human population variation should not correlate with erosion periods unless also accompanied by a climatic change which itself favours erosion (Butzer 1974; Butzer 1982). Climatic variation throughout the last glaciation and Holocene has been examined by many methods (Bradley 1985; Starkel 1987; Street-Perrott and Perrott 1990; Wijmstra et al. 1990;
Chappellaz et al. 1993; Huntley and Prentice 1993; Kutzbach et al. 1993; Roberts and Wright 1993; Ariztegui et al. 2000; Kallel et al. 2000; Enzel et al. 2003; Wick et al. 2003). These include oxygen isotope studies of ice and sediments, dendrochronology, pollen cores, glacial advances, lake levels, raised coral reefs, sea level curves, mass movement deposits, alluviation, harvest dates, written descriptions of climatic events and more recently direct climate recording.

Geomorphic evidence of valley glacier advances and retreats throughout the world’s active glacial areas has been used as a Holocene climate indicator by Rothlisberger (1986). Glaciers are sensitive barometers of climate change and they expand quickly in cooler periods. Rothlisberger collected all samples from similar sized valley glaciers and used the same laboratory for all the dating in an attempt at determining if advances were synchronous. Rothlisberger’s data indicates small climatic fluctuations have occurred throughout the Holocene. A plot of these glacial advances is shown in Figure 2.17 and it demonstrates a remarkable global synchronicity of events. The best data he gathered come from New Zealand and the European Alps and these show a remarkable similarity suggesting climate changes were synchronous in both hemispheres of the globe. One conclusion that may be drawn from this data set is that the moderate changes in climate that trigger the advances appear to occur synchronously around the global. Winstanley (1973) has indicated a link between increased winter-spring rainfall and general cooling of the northern hemisphere. However, there is no clear relationship between the pattern of glacial advance/retreat and alluvial activity in the Leipsokouki valley (see Figures 8.7 - 8.8). Also Holocene alluvial deposition in the valley is not seen between 8.1 and 5.9 cal kyr BP despite the fact that glacial advances appear as regular phenomena, in the early Holocene. They occur at intervals of 1,000 - 1,500 years, throughout the Holocene (Grove 1988).

Macklin et al. (1995) indicate moister climatic conditions in the early Holocene changing abruptly to drier conditions in the west but more gradually in the eastern Mediterranean after about 5,000 cal yrs BP. This confers quite well with the findings of Ariztegui et al. (2000) and also Kallel et al. (2000) who indicate greater river discharge and rainfall between approximately 6.8 – 9.8 cal kyr BP in the Adriatic and Italian mainland. Ballais (1995) also discusses greater humidity in the early Holocene between about 10 – 5 kyr BP in his study of Holocene alluvial terraces in Tunisia.
The study of oxygen isotopes, dust chemistry, conductivity and methane in ice cores has provided excellent data on global climate during the close of the last glaciation and the onset of the Holocene (Johnsen et al. 1992; Chappellaz et al. 1993; Mayewski et al. 1993; Taylor et al. 1993; Walker et al. 1999; Mithen 2003). Figures 8.7 and 8.8 provide a comparison between the oxygen isotope curve from Greenland (GRIP) and the colluvial and alluvial record in the Leipsokouki valley. Some of the climatic fluctuations noted in the Greenland ice cores have also been recognised in the Tibetan plateau, Barbados coral reefs and in Africa lake levels (Street-Perrott and Roberts 1983; Fairbanks 1989; Street-Perrott and Perrott 1990; Van Campo and Francois 1993). They have also been observed in recent ice cores from Antarctica (Steig et al. 1998). This suggests the climatic changes from full glacial in near interglacial and back again between 15 – 10 kyr BP are widespread climatic events. The late glacial climatic maximum (Bolling-Allerod interstadial) occurs in association with a period of soil colluvial deposition rich in charcoal (C6, C19). Perhaps the warmer and moister conditions aided soil creep and colluvial processes, however burning also seems to be part of the colluvial activity. It was not until the fluctuation back to drier and cooler conditions of the Younger Dryas stadial that the Syndendron alluvium is deposited, again in association with burning. However no significant alluvial deposition has been associated with the dramatic climatic change at the beginning of the Holocene where the climate changes from full glacial to interglacial conditions. The lack of significant alluvial deposition until 5.9 cal kyr BP suggests factors other than climate are important drivers of alluvial deposition in the Leipsokouki valley. They also suggest it is the swing from moist warm to dry-cool conditions which are associated with landscape instability whereas the reverse results in soil creep and colluvial activity on slopes. The pollen data from Lake Gramoutsii and the Drama Plain suggest the Younger Dryas stadial and the Bolling-Allerod interstadial may have exerted a vegetational change in northern Greece (Turner and Greig 1975; Willis 1992a). The open steppe of the late glacial period becomes partly invaded by oak trees before a return to the cold dry steppe vegetation during the 14 - 10 kyr BP period (Turner and Greig 1975; Willis 1992a). Also Turner and Sanchez-Goni (1997) indicate vegetational fluctuations in Epirus indicating sustained woodland expansion after about 15 kyr BP (close to the start of the Allerod-Bolling interstadial warm-wet) followed by a reduction in tree cover and open habitats (possibly the Younger Dryas
cool-dry) before a resurgence of deciduous woodland with the onset of postglacial conditions. They also note that vegetation reductions in the late glacial period are associated with erosion of coarse limestone debris of a freeze-thaw nature while Holocene erosion, associated with human-induced tree clearance resulted in silty clay sediments (Turner and Sanchez-Goni 1997). In the Leipsokouki valley the late glacial erosion is of a fine-textured nature and largely represents sheet wash, although some debris flow deposits also occur. The Leipsokouki erosion is also associated with fire events. The fine-textured nature and the landscape fires may hint at a partly anthropogenic cause rather than purely climate change to cool-dry conditions of the Younger Dryas. Turner and Goni (1997) also indicate opening-up of the vegetation after about 6,600 yr BP and this becomes more pronounced after about 4,000 yr BP and is associated with erosion of local basins. Willis (1997) indicates large-scale topsoil erosion after 4,300 yr BP onwards with herbaceous taxa becoming established around Klithi rock shelter Epirus.

Pollen data from Drama at Philippi indicates a mixed oak forest existed between 6500 and 2500 BC in northern Greece (Greig and Turner 1974). An increase in maquis vegetation was noted for the remainder of the Bronze Age, suggesting possible human disturbance. Clear evidence of vegetation change associated with human activity occurred from 1900 to 1360 BC when a distinct increase in olive occurs. In the following period up until 1000 BC olive pollen drops off but increases again during 1000-500 BC. The period 0-500 BC sees a drop off in olive pollen to a similar level as the periods 1360 - 1000 BC and 2500 - 1900 BC. This data suggest humans were gradually changing the native vegetation to include more cultivated species from the Bronze age until present (Greig and Turner 1974). If these data can be applied to north-western Greece and the Leipsokouki catchment they would suggest major denudement of the landscape did not occur until after ca. 4.0 kyr BP. This timing correlates with the onset of the Sirini A alluvial aggradation but says little about either the Amygdalies alluvial event (ca 5.9-4.4 cal kyrs BP) or the slope colluvium deposited at ca 5.0 cal kyr BP (C11 and P59) and ca. 7.5 cal kyr BP (C12) and debris flows at ca 6.5 and 7.5 cal kyr BP (C1, C11). In Grevena the Early Neolithic saw a large expansion in the number of sites, but sites are less common in the Middle and Late Neolithic (Wilkie 1993; Wilkie 1995). Willis and Bennett (1994) indicate the Neolithic agricultural revolution did not reach the Balkans until 6.0 kyr BP. In the
Leipsokouki the Early Neolithic is a well-represented period and it is during this time that the first Holocene alluvial deposit begins to form i.e., the Amygdalies alluvium which is preceded by debris flow deposits dating from 7.5 to 6.5 cal kyr BP. This alluvial deposit is known from only one well-dated site where it represents about 2 m of alluvium. However it is associated with slope activity that occurred between ca 7.5 and up to 5.0 cal kyr BP (C1, C11, C8 and P59).

Starkel (1983; 1987; 1991; 2003) has modelled hydrological changes in streams during the Holocene that are climatically controlled. His model of fluvial activity (see Figure 8.5) for the temperate zone is based on the premise that climatic fluctuations were reflected in parallel changes of river discharge (Qw) and sediment load (Qs). Depending on the leading factor (rise of Qw or Qs) during an active phase, there follows a tendency to either erosion or to aggradation (Starkel 1987; 2003). However a lack of synchronicity in alluvial fills deposited after 3,500 cal yr BP leads him to conclude anthropogenic factors affect the model due to accelerated erosion in this period. Later (Starkel 2003) indicates anthropogenic disturbance of the vegetation cover can be shown to have occurred from the early Neolithic period in central Europe, i.e., from about 6 kyr BP.

Starkel (1983) relates phases of gullying and alluvial fan development to periods of increased moisture and thus run-off. However in the Leipsokouki gullying does not appear as a significant process until sometime after about 4,150 cal yr BP (refer site C14) and more likely after 3,100 cal yr BP (site C3 and C4). Thus gullying in the study area falls largely within the period of anthropogenic disturbance mention by Starkel (1983; 2003). It is therefore not possible to conclude an increase in moisture as the cause of gullying when anthropogenic modification of soil, vegetation and drainage patterns has occurred. Such modification can greatly affect run-off and its local effectiveness at incision and gullying as shown in Figure 8.2 and Plates 8.1 and 8.2.

If the Syndendron (A & B), Amygdalies, Sirini (A, B & C) and Leipsokouki alluvial sequences were compared with Starkel's model they do not fit very well with his cycles. The Leipsokouki catchment is located in a continental type climate and so should conform with the model, which is partly based on data for the Danube, which
is 460 km to the north. The Syndendron A alluvium aggrades in a period (12.3 - 9.9 kyr BP) that Starkel identifies as largely erosional changing to aggrading braided streams after 10.5 kyr BP. Also Starkel (1983; 2003) indicates the late glacial-Holocene transition as a period of braided stream deposition while the Syndendron alluvium is dominantly meandering or overbank deposits. Thus this is a poor correlation between the Leipsokouki and the central European stream model in this period. The Amygdalies alluvium is also a poor fit as it coincides with a period of valley incision in Starkel’s model. However the Sirini alluvium fits the model although Starkel admits that in the mid to late Holocene the model has been influenced by anthropogenic factors (1983; 2003). The main conclusion of the comparison is the Starkel model is a poor fit for the Leipsokouki data. As the Starkel model is climate driven this suggests either the climate cycles of the two regions are significantly different (out of phase) or that other factors are important in controlling alluvial processes in the Leipsokouki valley.

There is only a weak correlation between the timing of mass movement deposits (colluvium, soil creep and debris flow) and the alluvial aggradation events during the Late Pleistocene and Holocene in the Leipsokouki. If there is a pattern, then it appears debris flow and sheet wash precede or are concurrently with alluvial aggradation and the soil creep follows alluvial events. This situation is not unexpected as during alluvial fan and terrace aggradation sediment will be readily transported from the slopes, via gullies and slope depressions, to the aggrading valley floor. Colluvial and creep deposition may then occur as the aggradation slows due to re-adjustment of over-steepened slopes generated during the incision, transport and valley aggradation phase. Debris flows may occur prior to and during the aggradation phase as incision of the slopes leads to undercutting of hill slope regolith and slope collapse. Debris flows at C11 and C6 appear to have directly contributed sediment to aggradation. However debris flows may also result from valley-wide incision and undercutting but not result in aggradation within the valley. Colluvial deposits also appear to underlie the Syndendron alluvium; these may relate to a period of warmer and moister conditions of the Bolling-Allerod climatic optimum (Fairbanks 1989; Chappellaz et al. 1993; Taylor et al. 1993; Steig et al. 1998; Mithen 2003). However they also contain abundant charcoal fragments in their topsoils that indicate landscape fires were an important factor.
Figure 8.5 Graph from Starkel 1987 (p329) showing types of sequences of change in the hydrological regime and sediment yield typical of central European valleys during the last 15,000 years. \( Q_w^+ = \) rise in channel-forming discharge, \( Q_w^- = \) decrease in discharge, \( Q_s^+ = \) rise in sediment load, \( Q_s^- = \) decrease in sediment load, \( E = \) erosion, \( A = \) aggradation, \( m = \) tendency to meandering, \( b = \) tendency to braiding. There is a poor fit for the data from the Leipsokouki valley which are marked by black bars signifying alluvial aggradation periods. Generally periods of aggradation in the Leipsokouki correlate with periods of incision in the model of Starkel.
Figure 8.6 Correlation of alluvial aggradation periods in the Mediterranean with the Leipsokouki catchment.
Figure 8.7 Correlation diagram between data from Grevena erosion-deposition cycles (B) and European Alps glaciers (A) and Oxygen isotope (temperature) curves for Greenland (C).
Figure 8.8 Correlation diagram between data form Grevena erosion-deposition cycles (B) and European Alps glaciers (A) and Oxygen isotope (temperature) curves for Greenland (C)
The Sirini alluvium is a three-stage alluvial deposit. Sirini A began aggrading in the Early-Middle Bronze Age before pausing, during which soil formation occurred. This was followed by the main component, Sirini B between 3.1 and about 2.1 cal kyr BP. At C16 there is evidence of a final phase of alluvial deposition between 2.1 and 1.7 kyr BP. The impact of human disturbance of the landscape in Northern Greece during the Bronze Age is shown in pollen data and the archaeological record of population and agricultural activities (Greig and Turner 1974; Chester 1991; Wilkie and Savina 1992; Willis 1992a; Wilkie 1993; Wilkie 1995; Wilkie and Savina 1997). The Iron Age through to Roman periods are also very well represented in the Grevena archaeological record (Wilkie and Savina 1992). This may well have resulted in an expansion of grazing, cultivation and tree cutting as indicated in written documents and archaeological evidence (including sheep vertebrae, burnt cereal grains, loom weights, storage jars).

The suggestion that human modification of the environment is important after ca 4.2 cal kyr BP and particularly after 3.1 cal kyr BP in the Leipsokouki is based on three main points:

1) The sudden increase in gravelly channel-type and finer overbank type-deposits providing up to 10 m of alluvial sediment, without an equally sudden climate change (Wright 1968; Greig and Turner 1974; Turner and Greig 1975; Wagstaff 1981; Rothlisberger 1986; Grove 1988; Wright 1993). Although drier climatic conditions were noted in Tibet, NE Africa and eastern Turkey at about this time (Street-Perrott and Roberts 1983; Van Campo and Francosie 1993; Enzel et al. 2003).

2) Indications of a high level of population at the time as shown by large numbers of Late Bronze Age, Iron Age, Hellenistic and Roman sites in the Nomos of Grevena, (Wilkie and Savina 1992) but also moderate numbers of Middle Bronze Age sites in the Leipsokouki Valley.

3) The evidence of deforestation and expansion of marquis vegetation as indicated by Greig and Turner (1974) and the abundance of macroscopic charcoal in the alluvial and colluvial sediments in the Leipsokouki catchment.
In the southern Argolid Pope and Van Andel (1984) observe four Holocene aggradations and these are commonly seen to follow major periods of occupation. They hypothesize that the erosion and aggradation phases follow the human abandonment of field terrace systems. The field terrace walls were erected to conserve soil and assist cultivation. On abandonment the walls collapse and decay and sediment is discharged into the streams and results in valley aggradation (Pope and Van Andel 1984). Their post-Classical alluvial aggradation correlates well with the Sirini B and many of the associated colluvial deposits (C16, C4, P47, P36) in the Leipsokouki catchment. Also the Ottoman alluvium of Pope and Van Andel would match the Leipsokouki alluvial and colluvial deposits.

However in the Leipsokouki valley the Holocene erosion-deposition cycles start during the Early-Middle Neolithic when debris flows and soil creep occur in the upper catchment and associated alluvial deposition occurs in the Late Neolithic (Amygdalies alluvium). The Early Neolithic is an important period in Grevena and heralds the start of agriculture in the region. Debris flows in the upper catchment continue until after 6.5 cal kyr BP and the Amygdalies alluvium commences at about 5.9 cal kyr BP (Late Neolithic) in the lower catchment. It is not difficult to imagine partial clearance of some upper slopes and the catchment divide that had moderately deep soils and abundant springs being very attractive for grazing and limited cropping (as they are today). However the side-slopes are very steep and clearance of the flatter upper slopes and catchment divide may have triggered greater infiltration and run-off leading to destabilisation of the adjacent valley slopes. The slopes throughout the catchment generate soil colluvium in the Late Neolithic and into the Early Bronze Age. This is closely correlated with a period of alluvial aggradation extending from the Late Neolithic and Early Bronze Age.

Work by Davidson (1980) on Melos in the Aegean suggests human induced soil erosion was under way by the Late Bronze Age and continued in following periods based on pollen and pedological evidence. Early-Middle Bronze age soil erosion was also noted in the Southern Argolid and the Argrive Plain in the Peloponnesus (Pope and Van Andel 1984; Finke 1988) and put down to human causes. The current study has indicated Middle to Late Bronze Age erosion in the form of the Sirini A alluvium and soil colluvial deposition in depressions and lower slopes. The soil colluvium is
well-structured, dark earthy material indicating the source was from well-developed relatively un-degraded soils (C11, P59, and P77).

**Neo-tectonics and seismic events**

An age estimate of the upper Plio-Pleistocene sediments, which lie beneath the Mersina surface is estimated at 730 kyr BP based on paleomagnetic dating by Doyle (1990). However Rassios (2004b) indicates mastodon bones found in a section above the town of Grevena are 200 kyr BP in age. Modern streams have incised up to 100 m below the Mersina surface indicating an incision rate of between 0.14 and 0.5 mm/year. If regional incision is in balance with uplift then these incision rates indicate an approximate uplift rate. This rate is low to moderate and suggests that tectonic activity is clearly a driver of regional down-cutting; it may not be a major factor in accelerated erosion associated with Holocene gullying and valley filling. An uplift rate of 0.14-0.5 mm/yr will only provide 2 – 7.5 m of uplift in the last 15,000 years which is not likely to induce the accelerated erosion present in the catchment that produced up to 15 m of sediment post 15 kyr BP. The direct effect of shaking associated with earthquakes is one possible mechanism for triggering landslides and is discussed by Rassios (2004a). Rassios states “I think most of the debris flows and landslides are more probably due to the regional uplift, with the earthquakes merely punctuating events. As well, the formations are pretty poorly consolidated. A year of torrential rain would probably set off as many landslides as an earthquake.” Rassios (2004b) indicates that it was only along the actual 1995 fault trace that a few earthquake induced landslides and some liquefaction occurred. However she also indicates some Grevena faults have been quite active throughout the Quaternary, despite no historic movements having been documented.

Chatzipetros et al. (1998) undertook paleo-seismic trenching studies along the Sarkina fault near Grevena which indicates Holocene seismic activity with a suggested periodicity of about 30,000 years. Such a wide recurrence interval makes it difficult to imply seismic activity as a major cause of the semi-continuous alluvial aggradation between 5,900 and 4,400 years and then again between 4,150 and 1,700 cal yr BP in this study. It also would seem unlikely that a seismic event could explain more than 14 m of alluvial aggradation associated with the Syndendron event when no alluvial aggradation has been reported following the major earthquake of 1995 that destroyed
over 4,000 buildings (Rassios 2004b). The author noted no new alluvial activity in the Leipsokouki valley post the 1995 Grevena earthquake. However some authors have noted the impact of seismic activity in Greece namely Jacobsen (Jacobsen 1976) who indicated that rock falls in the Frachthi cave at 3000 BC were possibly related to earthquakes. The close of the Minoan civilization has also been linked to earthquakes and volcanic activity.

In this study it is accepted the seismic activity has a major role to play in geomorphic processes, however the low rates of regional uplift suggest that seismic events are unlikely to be directly responsible for the majority of alluvial and colluvial events in the Leipsokouki. The only likely event that may relate to seismic activity is the C1 debris flow and perhaps the debris flows at C6 and C11. However, debris flows require significant lubrication and saturated soil conditions more likely to be associated with extremely wet weather conditions than an earthquake.

**Anthropogenic factors and soil erosion**

In the Leipsokouki catchment there is a landscape formed on the boundary of weakly consolidated Plio- Pleistocene sediments and moderately consolidated Tertiary marls. Such areas provide ideal conditions for human settlement with deep and very fertile soils, ample perennial springs on the Tertiary marls and good materials for stone tool making in the Plio-Pleistocene gravels. The valley narrows at the point at which they meet the Grevenetikos stream meaning it would provide an excellent site to herd/drive and hunt game. The valley also provides ample vantage points for hunting and defensive purposes.

It is clear from a soil development perspective that the rate of soil erosion increased dramatically after about 12.3 to 9.9 cal kyr BP and then again between 3.1 – 1.7 cal kyr BP. Periods of slope instability also occur in the upper catchment at 7.5 - 6.5 cal kyr BP, while smaller alluvial aggradation events occur at 9.4 – 8.0, 5.9 – 4.4, 4.15 – 1.7 and ca. < 0.5 - 0 cal kyr BP. The mature soil types of the valley are very dark brown to black vertisols and mollisols (Doyle 1990). Other key soil types are terra-rossas on calcareous sandstones in the upper catchment and reddish brown inceptisols occur on gravelly slopes in the lower catchment. The dark silt clay soils indicate a base rich, low leaching soil environment (Spiropoulou et al. 1983a; Spiropoulou et al.)
The soils that developed above the Syndendron alluvium are of this type, most developing by gradual accumulation of pedogenic materials by soil creep and slope wash processes. The soil creep and slope wash were at a sufficiently low rate at which development of a single dark brown soil profile of a “cumulate” nature developed. However accelerated sheet wash and colluvial processes after about 2.3 cal kyr BP produced calcareous, greyish or tan colluvium.

Sivignon (1983) states that the Hellenistic and Roman periods were an age when density of settlement increased in Macedonia placing pressure on the forestland. Support for anthropogenic causes of late Holocene aggradation events is seen by the rapid rate of infilling of the Thermaic Gulf between the Grecco-Roman and Late Roman periods (Figure 2.9, from Sivignon 1988). The Leipsokouki catchment forms part of the headwaters of the Haliakmon River which drains the Nomos of Grevena and it feeds into the Thermaic Gulf.

Reasons to suspect human impact in at least the post 3.1 cal kyr BP erosion and deposition are as follows:

1. The very rapid increase in sedimentation rate after 3.1 cal kyr BP with no major changes in climate suggest human disturbance of the landscape is a likely cause of erosion and deposition between the very Late Bronze Age and Late Roman period. Dedvok and Moszherim (1992) indicate the anthropogenic component vis natural component in suspended sediment yields are the greatest in the Mediterranean climatic-vegetation zone.

2. A high number of archaeological sites come from the Late Bronze Age to Roman periods and the majority of the sites are on the upper slopes and catchment divide, an area of deep fine textured soils and common springs. Evidence of grazing, growing of cereals, weaving and the use of fire appear to be important factors suggesting moderate levels of land use pressure in the periods mentioned above (Wilkie and Savina 1992; Wilkie 1993; Wilkie 1995).

3. The formation of gullies on convex components of the valley side-slopes suggests stock tracks and/or field boundaries may have led to run-off and incision in areas which normal shed run-off water (Plate 8.1 and Figure...
8.2). The variability in gully distribution also suggests pressure points in certain parts of the valley led to gully formation while adjacent areas remain unaffected (see Plate 7.15 and Figure 7.9).

(4) The high spatial diversity of the soil pattern as shown by Doyle (1990) is another factor that implicates human disturbance. The disrupted, chaotic soil pattern which commonly fails to follow typical changes in parent material and topography points to human interference with the soil mantle. This is because human impact can be concentrated at one area in the landscape causing soil disturbance and erosion while leaving other areas less affected.

(5) Chester (1991) has shown the very strong relationship between charcoal and sediment yield. This highlights the critical role of fire in this landscape disturbance. Charcoal is found in most soil sections younger than 15 cal kyr BP while the older sediments and paleosols of the catchment divide and Plio-Pleistocene sections have no charcoal.

The causes of the debris flow deposits dated to ca. 7.5 – 6.5 cal kyr BP cannot be determined although the presence of charcoal rich layers separating the deposits demonstrates fire may have caused vegetative loss prior to the land sliding. However, the slopes are very steep in these upper catchment areas and periods of wet weather may equally have led to lubrication and slope failure. Roberts and Wright (1993) indicate wetter conditions than present at around 6.0 cal kyr BP in northern Greece. However the debris flows contain large pieces of well-developed soil profile suggesting long periods of stability prior to the slope failure. This would suggest that they represent a significant disturbance to the landscape. The Early Neolithic was an important archaeological period in the valley and fire may have been a tool for grazing management which led to slope destabilisation.

The Amygdalies alluvium has between dated between 5.9 – 4.4 cal kyr BP. The alluvium has a relatively low sedimentation rate (1.2 mm/yr). The early part of the deposition occurs during the Late Neolithic which is not a major period of archaeological occupation in the region, although the Early Bronze Age has 12 sites in the Nomos (Wilkie and Savina 1992). Perhaps the event is a delayed response to the debris flow deposits that occurred in the upper catchment during the Early Neolithic.
Although Roberts and Wright (1993) have shown that northern Greece was slightly wetter than present at 6 kyr BP. This may have led to sediment transport from stores in the upper catchments to the lower parts of the valley.

The causal factors of the Syndendron alluvium are difficult to resolve. Although reasonably well dated, the interpretation of the cause of the deposit(s) is hampered by anomalies in climatic reconstructions and by variations in the timing of pollen data and correlation of late glacial climatic events from Europe and Greenland (ice cores) to northern Greece. Fire was clearly a feature that magnified this erosion-deposition event. But the causes of catchment fires have not been determined. It is suggested here that climatic amelioration in the late glacial may have encouraged human expansion in the area and with this exploitation an increased rate of burning. However, fire and drought may also have increased if the full extent of the Younger Dryas stadial were unleashed on the region as some pollen data suggest (Willis 1992a; Tzedakis 1993). The swing from wetter interstadial back to drier stadial conditions may have been a trigger for the deposition of the Syndendron alluvium. A grinding stone and hearths have been noted in a paleosol developed on the alluvium at 9.4 cal kyr BP. While beneath the slope wash which fed the Syndendron aggradation is an unusual pit dug into the paleosol at C13. This pit is filled with small ferruginised wood fragments of unknown origin (Plate 5.11 – 5.12), but perhaps anthropogenic.

Macklin et al. (2002) provide evidence of sedimentary records in several Mediterranean valleys extending back to 200 ka BP. They indicate the climatic factor as the main driver of river aggradation with cool-dry climatic periods leading to a reduction in forest cover and subsequent increased hill slope erosion and valley aggradation. The coolest and driest climatic period during the Last Glacial was at ca. 18 ka BP. Thus the Macklin et al. (2002) model would have predicted the Syndendron alluvium to be of this approximate age. However it does not form until after 15 ka when wetter warmer conditions of the late glacial warming occurred. The main alluvial deposit is likely to be even younger at 12.3 – 9.4 ka BP and thus spans the change from glacial to modern interglacial conditions. So while climate change cannot be ruled out as a causal factor it was a change from cool-dry to warm-wet which initiated its deposition not the reverse as Macklin et al. propose. However the absence of significant alluvial deposits from prior climate changes indicates that in the
Leipsokouki valley fire appears as an important contributing factor for the initiation of erosion and deposition. This pattern of fire use is confirmed from pollen and charcoal records from Grevena in the late Holocene (Chester 1991).

Figure 8.7 and 8.8 demonstrate the relationships between the broad archaeological record, two climatic records (glacial advances and Greenland ice cores) and the catchment data. The figures show the progressive increase in the number of sites in the archaeological record with the exception of the Archaic-Classical and the Byzantine periods. Figure 8.8 demonstrates the record of alluvial aggradation broadly follows that of the archaeological record in both timing and magnitude. Figure 8.6 provides a comparison with the data from the study and work by others in the Mediterranean. This figure also suggests a concentration of erosion events in the last 5 – 6 kyr BP with many local variations but in total a theme of local human impact controlling the variations. The current study supports the conclusion others have drawn, that human modification of the sensitive, rugged, Mediterranean landscape is a prime casual factor in erosion and deposition. The current work also strongly concurs with the relationship established by Chester (1991) in the region, that fire and sedimentation rate are strongly linked. The current study suggests this relationship may extend into the late Pleistocene. Figure 8.9 provides a summary model that indicates the progressive feed-back of cycles of erosion on the soil landscape system. The model indicates if erosion events are too regular then soil recovery will be insufficient thus subsequent erosion will be greater due to higher run-off, lower water and less vegetative cover.
Sheet and slope wash, debris flows, reduction in soil cover

**Event 1** – fire, drought, clearance of vegetation cover

**Recovery 1** soil formation and some soil creep

Thinner soils generate run-off earlier and in greater amounts, run-off concentrates in compacted areas and incises landscape

**Event 2** – fire, drought, clearance of vegetation cover

Rapid run-off causing gullying, braided stream deposits, followed by soil colluvial processes filling slope depressions

**Recovery 2** soil formation and some soil creep

**Landscape processes**

**STABLE** Soil formation, aeolian accession, weathering, leaching, SOM accumulation

**Soil, land properties**

Thick, dark or red, well structured soils with fine texture. Leaching of carbonate, formation of nodules Soils have high water holding capacity, productive vegetation

Fine sediment generation, valley filling with fine sediment and soil

Soils somewhat thinner, leaching of carbonates, accumulation of organic matter, well structured soils and fine textures. Soils have moderate water holding capacity

Soils thinner and rocky, highly calcareous, some leaching in upper part, accumulation of organic matter, Soils have reduced water holding capacity, increasing amounts of exposed bedrock

**Figure 8.9** Flow diagram showing the likely linking and flow-on impacts of erosion and deposition on soil development and further land degradation.
CHAPTER 9 Conclusions

A history of soil erosion, alluvial and colluvial deposition is presented for a small catchment in NW Greece. The role of climatic events, seismisity and human disturbance of the landscape has been examined.

It appears a major sedimentary deposit named the Syndendron alluvium was deposited in the valley floor during the closing phases of the last glaciation. The deposit is most likely associated with the climatic fluctuation known as the Younger Dryas stadial. Although a climatic cause for Syndendron alluvium seems the most likely scenario the event was accentuated by regular burning of the landscape after about 15 kyr BP. Prior to this no evidence of fires was discovered in the soils and sediments examined and it would seem the fires follow the arrival of humans in the valley. Palaeolithic stone tools have been found in the region indicating humans were present but their impact on the environment has generally been considered to be minor (Wilkie and Savina 1992). The fires were initially associated with soil creep and colluvial activity between about 15 -13 kyr BP during a period of warmer and moister climate known as the Bolling-Allerod interstadial. The regular fires which have been identified would be devastating to the vegetation cover in such a narrow and steep catchment. When associated with a return to drier cooler conditions in the Younger Dryas these fires could lead to the erosion and release of the large reserves of fine sediment held on the upper slopes and catchment divide. It has been shown that erosion of fine sediment, at least in part derived from the upper slopes and catchment divide, led to the deposition of the Syndendron alluvium between approximately 13 and 10 cal kyr BP. Thus the combined effects of drier conditions and burning of the landscape seems to have led to the hill slope destabilisation by debris flow and slope wash processes. These processes supplied sufficient sediment to cause alluvial filling of the valley to a depth of 15-20 m.

Following the hill slope erosion and deposition of the Syndendron alluvium the catchment seems to have been relatively stable as indicated by the development of moderately deep and well structured, fertile, black silty clay loam soils on the alluvium. Soil creep becomes an important process and continues to be so throughout most of the Holocene. This is probably a reflection of the higher soil moisture
conditions and the abundance of reactive minerals in the silty clay soils i.e., smectite serpentine, sepiolite and talc.

The relatively stable forested conditions in the early Holocene allowed the streams, at least in the upper catchment, to incise into the Syndendron alluvium. This is shown by debris flow deposits after about 7.5 cal kyr BP that occur only slightly above (1 – 2 m) the bedrock base of the modern stream level. In the lower catchment aggradation on the Syndendron surface resumed and a further 2 m of fine textured alluvium was deposited on the well-developed black alluvial soil sometime after 9.3 cal kyr BP. Perhaps this deposition was a response to debris flows in the upper catchment between \(ca\) 7.5 – 6.5 kyr BP. These debris flows contain large (4x1m), intact pieces of well developed soil profile similar in chemical composition to those found preserved on the catchment divide. They indicate wet soil conditions associated with fire and possibly tree clearance. Roberts and Wright (1993) indicate the climate in northern Greece was wetter than the present at 6 kyr BP. However the younger debris flows (< 6.6 cal kyr BP) also occur at a time of human activity associated with the introduction of agricultural systems in northern Greece and an important archaeological period in Grevena – the Early Neolithic (Wilkie and Savina 1992). At C11 a debris flow dated to after 7.5 cal kyr BP was followed by localised alluvial aggradation. But C1 indicates debris flows occurred until after 6.6 cal kyr BP. As these debris flows supplied sediment to the valley floor it seems likely they aided alluvial aggradation. However in the lower catchment alluvial aggradation did not occur until after 5.9 cal kyr BP suggesting a long delay in sediment transport from the upper catchment to the lower.

Further alluvial deposition occurs after \(ca\) 4.15 cal kyr BP and this accelerates dramatically after 3.1 cal kyr BP with more than 6 m of sediment being deposited after this date. The Sirini alluvial deposition continues until at least 2.0 cal kyr BP as dated 1m from the top of the unit in the lower catchment, but probably till 1.7 cal kyr BP as indicated by colluvium which buried the alluvium in the mid catchment. The alluvial deposition coincides with a series of colluvial deposits on the valley sides dated between 5 kyr and 1.3 cal kyr BP. The Sirini A alluvium and the colluvial activity at \(ca\) 5 cal kyr BP coincide with the Early Bronze Age which is an important archaeological period in the Grevena region. The very dramatic acceleration in
alluvial deposition, a five times increase on prior aggradation events, after 3.1 kyr coincides with the Late Bronze Age and Iron Age both of which are very well represented archaeological periods in Grevena. This suggests major landscape disturbance was associated with one of the busiest periods in the Grevena archaeological record. The absence of any significant climate changes in this period lends strong support to an anthropogenic cause. The Sirini B alluvium is associated with slope incision and also colluvial activity on the surrounding slopes between ca. 3 – 1.3 cal kyr BP. Re-incision of the Sirini alluvium occurred some time after 1.7 cal kyr BP and thin and incipient A/C soils formed on the alluvium in sites where it was not covered by colluvium.

The colluvial deposits younger than about 2.5 cal kyr BP are highly calcareous, stony and have light grey or buff colours indicating they are derived from subsoils and regolith. This indicates parts of the local landscape had become severely degraded, a conclusion supported by the fact the deposits commonly fill prior gullies.

In the modern valley floor a 1 – 4 m thick alluvial deposit occurs. It was named the Leipsokouki alluvium by Doyle (1990) and has very weakly developed A/C soils formed on it. The unit was radiocarbon dated as modern (<150 years) using charcoal taken from the upper part of a section of fine textured alluvium. However the presence of pot sherds of Ottoman period at other sites indicates it is less than 500 years old. Certainly hill slope erosion and deposition processes where active between ca. 700 – 400 cal yr BP as indicated at sites C2 and P40.

The regular association of alluvial and colluvial activity and important (populous) archeological periods in the mid and late Holocene is taken as a strong indication that human modification of the vegetation and land use in the valley is the more likely cause of the accelerated erosion and deposition. The climate history as indicated by pollen and glacier records during the Holocene do not match well with the erosion and depositional cycles determined. Seismic activity appears to be of insufficient magnitude to be taken as a significant factor during the last 15,000 years.

The causal factors of erosion and deposition events of the late glacial are more difficult to determine. However climate change from warmer-wetter (Allerod-Bolling
interstadial) to cooler-drier (Younger Dryas stadial) as documented in other part of Europe and in Greenland are associated with major alluvial aggradation and hill slope erosion in the Leipsokouki valley. However these climatic fluctuations were also associated with a significant increase in landscape fires pointing to a partly anthropogenic cause for this erosion.

It seems clear further work on dating deposits in the Leipsokouki valley and the neighbouring regions will be critical in crystallising the soil stratigraphic record developed in this study. This work needs to be supported by continued research on the archaeological and pollen record, in particular those records associated with the Upper Paleolithic and Mesolithic periods.
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## Appendix 1  Radiocarbon dates for soils and sediments in the Leipsokouki catchment Grevena Greece

<table>
<thead>
<tr>
<th>Wk No.</th>
<th>Site</th>
<th>Name (L, M, U catch)</th>
<th>dC13</th>
<th>% Modern</th>
<th>Result</th>
<th>Calibrated (&gt;95% Prob)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Soil forming on Lepsokouki alluvium</strong>&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk9926</td>
<td>C18a</td>
<td>Leipsouki All. (Mid)</td>
<td>-24.9 +/- 0.2</td>
<td>100.7 +/- 1.4</td>
<td>&gt;Modern</td>
<td>140 ± 130</td>
</tr>
<tr>
<td>Wk 9813</td>
<td>C2a</td>
<td>Slope deposit on Sirini</td>
<td>-24.2 +/- 0.2</td>
<td>96.2 +/- 0.5</td>
<td>312 +/- 38 BP</td>
<td>380 ± 90</td>
</tr>
<tr>
<td>Wk1486</td>
<td>P40</td>
<td>Tsifliki hill slope (Up)</td>
<td>-26.0 +/- 0.2</td>
<td>91.1 +/- 0.8</td>
<td>750 +/- 70 BP</td>
<td>675 ± 125</td>
</tr>
<tr>
<td>Wk1484</td>
<td>P36</td>
<td>Mega Sirini coll. (Mid)</td>
<td>-24.0 +/- 0.2</td>
<td>83.9 +/- 0.5</td>
<td>1,410 +/- 50 BP</td>
<td>1,390 ± 130</td>
</tr>
<tr>
<td>Wk 9921</td>
<td>C16a</td>
<td>Colluvium on Sirini</td>
<td>-24.2 +/- 0.2</td>
<td>79.9 +/- 0.5</td>
<td>1,804 +/- 47 BP</td>
<td>1,735 ± 135</td>
</tr>
<tr>
<td>Wk1586</td>
<td>P47</td>
<td>Paleokastro area (Mid)</td>
<td>-25.4 +/- 0.2</td>
<td>76.2 +/- 0.7</td>
<td>2,190 +/- 70 BP</td>
<td>2,175 ± 175</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Greyish brown colluvial deposits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk1483</td>
<td>P11</td>
<td>IIAu2, Paleokastro (Mid)</td>
<td>-24.6 +/- 0.2</td>
<td>71.9 +/- 1.7</td>
<td>2,650 +/- 200 BP</td>
<td>2,750 ± 600</td>
</tr>
<tr>
<td>Wk9820</td>
<td>C11c</td>
<td>Tsifliki Part 2 (Upper)</td>
<td>-25.2 +/- 0.2</td>
<td>57.6 +/- 1.0</td>
<td>4,429 +/- 138 BP</td>
<td>5,050 ± 450</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dark brown soil-like colluvial deposits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk9815</td>
<td>C4a</td>
<td>Top Sirini all. (Low)</td>
<td>-24.2 +/- 0.2</td>
<td>77.5 +/- 0.5</td>
<td>2,047 +/- 56 BP</td>
<td>2,090 ± 60</td>
</tr>
<tr>
<td>Wk9922</td>
<td>C16b</td>
<td>Soil on alluvium</td>
<td>-24.2 +/- 0.2</td>
<td>75.1 +/- 0.4</td>
<td>2,302 +/- 47 BP</td>
<td>2,295 ± 145</td>
</tr>
<tr>
<td>Wk1579</td>
<td>P52</td>
<td>Mid Sirini all. (Mid)</td>
<td>-24.6 +/- 0.2</td>
<td>74.8 +/- 0.6</td>
<td>2,330 +/- 70 BP</td>
<td>2,450 ± 300</td>
</tr>
<tr>
<td>Wk9814</td>
<td>C3a</td>
<td>Base Sirini all (Mid)</td>
<td>-25.7 +/- 0.2</td>
<td>70.7 +/- 1.1</td>
<td>2,785 +/- 128 BP</td>
<td>3,025 ± 325</td>
</tr>
<tr>
<td>Wk9908</td>
<td>C4b</td>
<td>Base Sirini all. (Low)</td>
<td>-25.0 +/- 0.2</td>
<td>69.3 +/- 1.2</td>
<td>2,946 +/- 146 BP</td>
<td>3,100 ± 350</td>
</tr>
<tr>
<td>Wk9919</td>
<td>C14</td>
<td>Base Sirini all. (Mid)</td>
<td>-25.2 +/- 0.2</td>
<td>62.3 +/- 1.3</td>
<td>3,797 +/- 165 BP</td>
<td>4,150 ± 500</td>
</tr>
</tbody>
</table>

---

1. Soils and sediments from the Leipsokouki catchment in Grevena, Greece, are dated using radiocarbon methods. The table lists samples from various sites, including soils forming on Lepsokouki alluvium, greyish brown colluvial deposits, dark brown soil-like colluvial deposits, and Sirini alluvium. Each sample includes information on its designation, location, and radiocarbon results, providing insights into the site's chronological history.
### Amydalyes Alluvium

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soil Type</th>
<th>Stratigraphy</th>
<th>Depth (m)</th>
<th>Age (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk9818</td>
<td>C8d</td>
<td>Upper section, (Lower)</td>
<td>-25.9 +/- 0.2</td>
<td>61.0 +/- 1.4</td>
</tr>
<tr>
<td>Wk9911</td>
<td>C8c</td>
<td>1st buried soil (Lower)</td>
<td>-22.7 +/- 0.2</td>
<td>59.8 +/- 0.3</td>
</tr>
<tr>
<td>Wk9910</td>
<td>C8b</td>
<td>2nd buried soil (Lower)</td>
<td>-25.1 +/- 0.2</td>
<td>55.7 +/- 1.1</td>
</tr>
<tr>
<td>Wk9817</td>
<td>C8a</td>
<td>Basal alluvium (Lower)</td>
<td>-25.7 +/- 0.2</td>
<td>52.7 +/- 1.2</td>
</tr>
</tbody>
</table>

### Dates from landslides containing large intact block of reddish soil

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soil Type</th>
<th>Stratigraphy</th>
<th>Depth (m)</th>
<th>Age (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk9812</td>
<td>C1a</td>
<td>Tsifliki Part 1 (Upper)</td>
<td>-23.6 +/- 0.2</td>
<td>49.1 +/- 0.9</td>
</tr>
<tr>
<td>Wk9819</td>
<td>C11a</td>
<td>Tsifliki Part 2 (Upper)</td>
<td>-23.5 +/- 0.2</td>
<td>43.9 +/- 0.5</td>
</tr>
<tr>
<td>Wk9918</td>
<td>C12c</td>
<td>Tsifliki Part 3 (Upper)</td>
<td>-23.7 +/- 0.2</td>
<td>43.8 +/- 0.8</td>
</tr>
</tbody>
</table>

### Soils developed above the Syndendron alluvium

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soil Type</th>
<th>Stratigraphy</th>
<th>Depth (m)</th>
<th>Age (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk1582</td>
<td>P59</td>
<td>IIIAb (Mid)</td>
<td>-24.5 +/- 0.2</td>
<td>57.8 +/- 0.4</td>
</tr>
<tr>
<td>Wk9925</td>
<td>C17c</td>
<td>Buried coll soil (Mid)</td>
<td>-25.6 +/- 0.2</td>
<td>40.7 +/- 0.2</td>
</tr>
<tr>
<td>Wk9914</td>
<td>C9c</td>
<td>Upper Black Soil (Mid)</td>
<td>-21.3 +/- 0.2</td>
<td>40.3 +/- 0.3</td>
</tr>
<tr>
<td>Wk1485</td>
<td>P37</td>
<td>IIIAb1 (Lower)</td>
<td>-26.2 +/- 0.2</td>
<td>35.2 +/- 0.7</td>
</tr>
<tr>
<td>Wk9917</td>
<td>C12b</td>
<td>Tsifliki (Upper)</td>
<td>-24.9 +/- 0.2</td>
<td>33.4 +/- 0.2</td>
</tr>
</tbody>
</table>

### Syndendron alluvial sediments

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soil Type</th>
<th>Stratigraphy</th>
<th>Depth (m)</th>
<th>Age (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk9923</td>
<td>C17a</td>
<td>Syndendron Fan (Mid)</td>
<td>-25.2 +/- 0.2</td>
<td>23.0 +/- 0.6</td>
</tr>
<tr>
<td>Wk9915</td>
<td>C11b</td>
<td>Tsifliki Part2 (Upper)</td>
<td>-24.3 +/- 0.2</td>
<td>28.3 +/- 0.3</td>
</tr>
</tbody>
</table>

### Soil beneath the Syndendron alluvium or associated hillslope wash

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soil Type</th>
<th>Stratigraphy</th>
<th>Depth (m)</th>
<th>Age (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk9916</td>
<td>C12a</td>
<td>Tsifliki (Upper)</td>
<td>-24.6 +/- 0.2</td>
<td>30.3 +/- 0.2</td>
</tr>
<tr>
<td>Wk9821</td>
<td>C13a</td>
<td>Paleokastro For. (Mid)</td>
<td>-24.2 +/- 0.2</td>
<td>27.2 +/- 0.6</td>
</tr>
<tr>
<td>Wk9927</td>
<td>C19a</td>
<td>Soil under Syn (Mid)</td>
<td>-24.2 +/- 0.2</td>
<td>22.9 +/- 0.2</td>
</tr>
<tr>
<td>Wk9816</td>
<td>C6a</td>
<td>Soil under Syn (Mid)</td>
<td>-13.4 +/- 0.2</td>
<td>21.3 +/- 0.8</td>
</tr>
</tbody>
</table>

### Dates which appear to be wrong

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soil Type</th>
<th>Stratigraphy</th>
<th>Depth (m)</th>
<th>Age (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk9912</td>
<td>C9a</td>
<td>P1 Basal sloping (Mid)</td>
<td>-25.7 +/- 0.2</td>
<td>51.2 +/- 0.4</td>
</tr>
</tbody>
</table>
Appendix 2  Soil profile descriptions from Doyle (1990)

SOIL PROFILE 11
Location:- Edge of the Syndendron terrace, near Paleokastro, Grevena
Exposure type:- Cutting, terrace edge  Elevation:- 690 m
Erosion:- Gullying, sheet & rill  Drainage:- Moderate
Physiography:- At the edge of sloping Syndendron terrace, slope angle 6°, aspect NE
Parent material:- Very dark brown pedogenic colluvium from up-slope soils contains
Notes:- Iron Age pot sherds, dated at 2,650 + 200 years BP Wk 1483.

C 11 - 0 cm,  Dry; recent bulldozed material from construction of small farm road;

Au1 0 - 50 cm
Slightly moist; 10YR 3/1 (moist); silty clay loam; moderately developed coarse blocky
breaking to moderately developed medium blocky structure; sticky; plastic; firm moist
consistence; very firm dry consistence; un cemented; no clay cutans; no mottles; few very fine
nODULES of pedogenic carbonate; common very fine and fine roots; few gravels floating in soil
matrix; scattered Iron age pot sherds; react 10% HCl = nil; diffuse boundary;

Au2 50 - 95 cm,
Slightly moist; 10YR 3/2 (moist); silty clay loam; moderately developed coarse blocky
breaking to moderately developed medium blocky structure; sticky; very plastic; firm moist;
very firm dry consistence; un cemented; no clay cutans; no mottles; common fine nODULES of
pedogenic carbonate; common very fine + fine roots; few gravels floating in matrix; scattered
Iron age pot sherds; react 10% HCl = moderate; indistinct smooth boundary;

ACK 95 - 125 cm,
Slightly moist; 10YR 3/3 (moist); silt loam; massive breaking to a moderately developed
medium and coarse blocky structure; sticky; plastic; firm moist consistence; many fine
nODULES (2-3 mm) of carbonate plus fine veins of 5Y 9/2; very weakly cemented; few very
fine roots; few gravels floating in soil matrix; odd fragment of Iron age pottery; react to 10%
= strong to very strong; indistinct smooth boundary;

Ck 125 - 150+ cm,
Slightly moist; 2.5Y 4/2; massive breaking to weak coarse blocky structure; slightly sticky;
plastic; firm moist; very weakly cemented by pedogenic carbonate; many fine nODULES and
stock work of carbonate 2.5Y 6/4; no roots; no mottles; few gravels floating in matrix; react
to 10% = very strong;

SOIL PROFILE 30
Location:- Leipsokouki river bed 1 km downstream of Panagia on 6 m terrace (S4B)
Exposure type:- Cutting in terraces edge  Elevation- 630 m
Soil taxonomy:- Xerofluvent-Xerochrept  Common name:- Recent alluvial soil
Erosion:- Stream bank  Drainage:- Rapidly permeable
Physiography:- Surface of a Late Holocene terrace (6 m), slope angle 0°
Parent material:- Alluvial sands and silts on gravels which overlie buried soil on alluvium
Notes:  Au2 horizon one very rounded piece of pottery. Also see Section 4B.

Au1 0 - 3 cm,
Dry; 2.5Y 4/2 (dry); 2.5Y 3/1 (moist); fine sand to loamy fine sand; weakly developed very
fine blocky structure plus single grained structure; non sticky; non plastic; loose to very weak
dry soil strength; very weak dry ped strength; uncemented; no coatings or nodules; abundant very fine and fine roots; no stones; distinct smooth boundary;

Au2 3 - 20 cm,
Dry; 2.5Y 6/2 (dry); 10YR 4/2 (moist); very few very fine faint carbonate specks (disseminated); fine sandy loam; moderately developed medium blocky structure breaking to moderately developed fine nut; slightly sticky; slightly plastic; friable; moderately firm dry soil and dry ped strengths; few thin clay coatings on root channels; many very fine roots; common unweathered to weakly weathered sub-rounded pebbles of sandstone; sharp irregular boundary;

C1 20 - 95 cm,
Dry; 5Y 7/3 (dry); 2.5Y 4/3 (moist); very few very fine faint carbonate flecks; sandy loam; massive breaking to weakly developed medium to coarse platy/blocky; non sticky; very slightly plastic; very friable; moderately firm dry soil and dry ped strengths; no coatings; common medium roots; no stones; distinct smooth boundary;

C2 95 - 250 cm,
Layered alluvium; silty alluvial unit 95 - 120 cm; on sand 120 - 190 cm; on gravel 190 - 250 cm;

Ab 250 - 275 cm, (thickness varies laterally from 10 cm to 70 cm)
Dry; 10YR 4/2; many fine distinct 7.5YR 4/6 mottles; fine sandy loam; moderately developed coarse blocky structure breaking to moderately developed fine and medium blocky structure;

SOIL PROFILE 33
Location:- Leipsokouki river bed 1 km downstream of Panagia on 1.2 m terrace
Exposure type:- Cutting in terraces edge Elevation- 630 m
Soil taxonomy:- Xerofluvent-Xerochrept Common name:- Recent alluvial soil
Erosion:- Stream bank erosion Drainage:- Rapidly permeable
Physiography:- Surface of a Late Holocene terrace (6 m), slope angle 10, aspect open
Parent material:- Alluvial sands and silts on gravels

Aj 0-4 cm,
5Y 7/2 dry; 5Y 5/2 moist fine sand; single grain plus very weak fine blocky structure; non sticky; non plastic; loose; very weak dry ped strength; many fine and very fine roots; indistinct smooth boundary;

C1 4-50 cm,
5Y 7/2 dry; 5Y 4/2 moist; banded fine and medium sands; massive breaking to single grain; non sticky; non plastic; friable; very weak; common very fine roots; indistinct smooth boundary;

C2 50-60 cm,
5Y 8/2 dry; 5Y 4/2 moist banded fine sands and silts; otherwise similar to C1; few very fine roots; distinct smooth boundary;

C3 60-80 cm,
5Y 8/2 dry; 5Y 4/2 moist; clast supported; rounded granules (2-4 mm) and fine pebbles (4-16 mm) with sandy matrix; single grain; loose; indistinct wavy boundary;
C4 80-120 cm;
5Y 6/2 dry; 5Y 7/2 moist; clast supported; rounded pebbles and cobbles (16-64 mm) of mostly sandstone with some mudstone and ?Late, Hellenistic? rounded pottery fragments, with a sandy matrix;

SOIL PROFILE 36
Location:- Syndendron, down gravel road from Mega Sirini
Exposure type:- Road cutting Elevation- 620 m
Soil taxonomy:- Xerorthent Common name:- Young colluvial soil
Erosion:- Stream bank Drainage:- Moderately permeable
Physiography:- Colluvium filling depression cut in terrace alluvium, slope <10°, aspect W
Parent material:- Thick colluvia (<1.5 Ka BP) inset into hollow cut into an alluvial terrace

Aj 0 - 10 cm,
Dry; 2.5Y 6/2 (dry); 2.5Y 4/2 (moist); silt loam; weakly developed very fine nut plus weakly developed very fine granular structure; slightly sticky; plastic; very friable; very weak dry soil and dry ped strengths; no coatings; common very fine and fine roots; common weakly weathered sub-angular granules of silt stone; react to 10% HCl = very strong; indistinct smooth boundary;

Bj 10 - 42 cm,
Dry; 5Y 6/2 (dry); 5Y 4/2 (moist); fine sandy loam; weakly developed very coarse nut and blocky structure breaking to weakly developed fine and very fine blocky structure; slightly sticky; plastic; friable; moderately firm dry soil strength; moderately weak dry ped strength; few faint clay coatings on worn channels; few medium roots; common weakly weathered sub-rounded and sub-angular granules of mudstone; react to 10% HCl = very strong; distinct smooth boundary;

C 42 - 54 cm,
Dry; 2.5Y 6/2 (dry); 2.5Y 4/2 (moist); gravelly gritty loam sand; single grained plus very weakly developed very fine blocky structure; non sticky; non plastic; loose; very weak dry soil and dry ped strengths; no coatings; few very fine roots; profuse weakly weathered sub-rounded and sub-angular pebbles and granules of mudstone; react to 10% HCl = very strong; distinct smooth boundary;

IIIBuried colluvial unit 54 - 172 cm,
Dry; 2.5Y 6/2 (dry); 10YR 4/1.5 (moist); silt loam; moderately developed coarse blocky structure breaking to moderately developed fine and medium blocky structure; slightly sticky; plastic; friable; moderately firm dry soil strength; very firm dry ped strength; common faint organic 10YR 5/2 coatings plus common distinct clay coatings on root channels; few very fine roots; few weakly weathered sub-rounded and sub-angular granules of mudstone; react to 10% HCl = moderate; distinct smooth boundary;

IIIAb 172 - 184 cm, (thin weakly developed buried soil forming on floor of incised channel)
Dry; 10YR 5/1 (dry); 10YR 3/1 (moist); common fine faint veinlets of carbonate and specks/nods; silt loam; moderately developed coarse blocky structure breaking to moderately developed medium blocky structure; slightly sticky; plastic; friable; very firm dry soil strength; moderately firm dry ped strength; no roots; few weakly weathered sub-rounded granules of mudstone; react to 10% HCl = moderate; distinct smooth boundary;

IIIBb 184 - 191 cm,
Dry; 2.5Y 7/3 (dry); 2.5Y 5/3 (moist); common fine faint carbonate specks/nods; silt loam; massive; slightly sticky; plastic; very friable; moderately strong dry soil strength; no roots;
few moderately weathered sub-rounded granules of mudstone; react to 10% HCl = strong; distinct smooth boundary;

**IVC 191 - 210 + cm, (alluvium)**
Dry; 5Y 7/2 (dry); 2.5Y 6/3 (moist); silt loam and very fine sand interbeded with 10 - 15 cm thick layers of granules; massive plus single grained; slightly sticky; plastic in part; very friable; very weak dry soil strength; profuse weakly weathered sub-rounded granules of mudstone (alluvium); react to 10% HCl = very strong;

**Notes:** Radiocarbon date on IIIAb gives and age of 1410 + 50 years

**SOIL PROFILE 37**
Location:- Mega Sirini, edge of 10.5 m terrace, 100 m downstream of road-bridge
Elevation- 580 m
Soil taxonomy:- Pelloxerert
Common name:- Dark swelling soil
Erosion:- Stream bank slump
Drainage:- Slowly permeable
Physiography:- 10.5 m sloping terrace tread, exposed by slump, slope angle 3-50, aspect NE
Parent material:- Colluvium of pedogenic origin on 10 m of sandy-silty alluvium containing two buried soils, radiocarbon date for basal paleosol dated to 9.3 cal kry BP

**Au1 0-10 cm,**
Dry; 10YR 4/2 (dry); 10YR 3/1 (moist); silty clay loam; strongly developed very fine and fine granular structure; sticky; plastic; very friable; loose; moderately weak dry ped strength; few thin clay coatings on peds in lower part of horizon; many fine and very fine roots; few subrounded granules; react to 10% HCl = nil; distinct smooth boundary;

**Au2 10-80 cm,**
Dry; 10YR 5/3 (dry); 10YR 4/3 (moist); silty clay loam; strongly developed coarse plus medium blocky structure; sticky; plastic; firm; very firm; very strong dry ped strength; common thin clay coatings on ped faces; many sicken side, some are intersecting; few very fine faint flecks and nodules of CaCO3; few very fine roots; few weakly weathered subrounded granules; react to 10% HCl = weak; indistinct smooth boundary;

**A/C 80-105 cm,**
Dry; 2.5YR 6/3 (dry); 2.5Y 5/3 (moist); silty clay loam; moderately developed coarse + med blocky structure; sticky; plastic; friable; very firm; moderately strong dry ped strength; few very fine faint flecks and nodules of CaCO3; few very fine roots; few weakly weathered subrounded granules; react to 10% HCl = mod; indistinct smooth boundary;

**Ckj 105-160 cm,**
5Y 7/3 (dry); 5Y 6/3 (moist); silt; massive; slightly sticky; slightly plastic; friable; very strong; rigid dry ped strength; few distinct organic coatings down cracks; common very fine nodules of CaCO3 in faint bands; react to 10% HCl = very strong;

**IIAb1 160-170 cm,**
10YR 4/2 (dry); 10YR 3/1 (moist); silt loam; moderately developed fine blocky structure; sticky; plastic; firm; very strong dry soil & dry ped strengths; common fine nods of CaCO3; few subrounded pebbles; react to 10% HCl = strong; distinct smooth boundary;

**IIckj2 170-217 cm,**
5Y 7/3 (dry); 2.5Y 6/3 (moist); silt loam; massive; slightly sticky; slightly plastic; very friable; moderately strong dry soil strength; few humus stains down cracks; com - many v. fine distinct nods of CaCO3; react to 10% HCl = v strong; distinct smooth boundary;
IIIAb1 217-225 cm,
10 YR 4/2 (dry); 10YR 3/1 (moist); silty clay loam; strongly developed fine blocky structure;
sticky; plastic; firm; moderately firm; moderately strong dry ped strength; v.few faint coats of
CaCO₃; common distinct clay and organic coatings and slicken-sides; few subrounded
pebbles; few fine coats of CaCO₃; react to 10% HCl = weak; indistinct smooth boundary;

IIIAb2 225-245 cm,
2.5Y 5/2 (dry); 2.5Y 4/2 (moist); silty clay loam; strongly developed medium + fine blocky
structure; sticky; plastic; firm; common faint clay and organic coatings in pores & cracks;
few fine coats & flecks of CaCO₃; react to 10% HCl = very weak; indistinct smooth
boundary;

Ckj 245-320 cm+,
5Y 7/2 (dry); 5Y 5/3 (moist); silt loam, grading into fine sands granule lenses some
composed of abundant CaCO₃ nodules of up to 1 cm in dia; react to 10% HCl = very strong;

Notes: Total thickness of alluvium is not known but it is greater than 9 m, and is mostly fine
alluvium with lenses or beds or granules (2-4 cm).

SOIL PROFILE 38
Location:- Opposite Mega Sirini, site is adjacent to large amphitheatre gully
Exposure type:- Pit Elevation- 670 m
Soil taxonomy:- Pelloxerert Common name:- Dark swelling clay
Erosion:- Stream bank Drainage:- Rapidly permeable
Physiography:- Surface of an intermediate sloping strath 50, aspect NE
Parent material:- Colluvium of pedogenic origin

Ap1 0 - 4 cm,
Dry; 10YR 4/2 (dry); 10YR 3/1 (moist); silty clay loam; moderately developed very fine
granular structure plus moderately developed fine nut structure; sticky; plastic; friable - firm;
loose dry soil strength; very firm dry ped strength; no coatings; many very fine roots; no
stones; distinct smooth boundary;

Ap2 4 - 30 cm,
Dry; 10YR 4/2 and 5/2 (dry); 10YR 4/2 (moist); silty clay loam; massive plus strongly
developed extremely coarse prismatic structure; very sticky; plastic; extremely firm; rigid dry
soil and dry ped strengths; common distinct organic 10YR 3/1 coatings; common intersecting
slicken-sides; common very fine roots; no stones indistinct irregular boundary;

Ap3 30 - 80 cm,
Slightly moist; 10YR 5/3 (as is); 10YR 4/3 (moist); very few medium soft chalky carbonate
nodules; silty clay loam; weakly developed fine and medium blocky structure; slightly sticky;
slightly plastic; friable; very weak dry soil and dry ped strengths; common distinct organic
10YR 3/1 coatings; few very fine roots; no stones; indistinct irregular boundary;

A/Ck1 80 - 105 cm,
Slightly moist; 10YR 4/3 (as is) and white; many medium soft chalky carbonate nodules;
heavy silt loam; weakly developed fine and medium blocky structure; slightly sticky; plastic;
friable; very weak dry soil and dry ped strengths; common distinct clay and Fe/Mn coatings
also carbonate; few very fine roots; no stones; indistinct irregular boundary;
Ckj 75 - 120 cm,
Slightly moist; 2.5Y 3/2 to 4/2 (as si); 2.5Y 4/2 (moist); loamy fine sand; massive breaking to single grained; non sticky; slightly plastic; very friable; very weak dry soil and dry ped strengths; common distinct Fe/Mn and carbonate nodules; no roots; common strongly weathered granules of mudstone; diffuse boundary;

C1  120 - 160 cm,
Slightly moist; 2.5Y 4/3 (as is); 10YR 4/3 (moist); loamy coarse sand; single grained; non sticky; slightly plastic; loose; loose dry soil and dry ped strengths; common distinct Fe/Mn and carbonate nodules; common moderately weathered sub-rounded granules of mudstone;

C2 160 cm +
Slightly moist; 2.5Y 4/3 (as is); 2.4Y 4/2 (moist); gritty loamy coarse sand; single grained; many sub-rounded granules;

SOIL PROFILE 40
Location:- Upper catchment, above Tsifliki road leading down to Tsifliki.
Exposure type:- Cutting, road side Elevation: 830 m
Soil taxonomy:- Inceptisol Common name:- Yellow brown earth
Erosion:- Gullying & rill ubiquitous Drainage:- Moderately permeable
Physiography:- Midslope of hillside, moderately dissected by gullies, slope 25°, aspect NE
Parent material:- Two phases of colluvium over mudstone, basal soil dated at 730 + 70 years BP.

L  2 - 0 cm,  Dry; 7.5YR 3/2 (dry); oak leaves; loose; distinct smooth boundary;

Ah  0 - 3 cm,  Dry; 7.5YR 4/2 (dry); 7.5YR 2/2 (moist); silt loam; moderately developed fine and very fine nut structure; non sticky; slightly plastic; loose; moderately weak dry soil and dry ped strengths; common distinct organic stains on peds; many very fine and medium roots; few weakly weathered sub-angular and angular pebbles of siltstone; distinct smooth boundary;

Bw1  3 - 25 cm,
Dry; 10YR 5/3 (dry); 10YR 4/3 (moist); silt loam; strongly developed medium blocky structure breaking to strongly developed fine nut; slightly sticky; plastic; friable; moderately firm dry soil and dry ped strength; few; faint organic stains down cracks; many fine and medium roots; common weakly weathered angular pebbles of siltstone and sandstone; indistinct smooth boundary;

Bw2  25 - 80 cm,
Dry; 10YR 5/3 (dry); 10YR 4/3 (moist); heavy silt loam; strongly developed medium blocky structure breaking to strongly developed fine blocky structure; slightly sticky; very plastic; very friable; moderately firm dry soil strength; very firm dry ped strength; no coatings; many fine and medium roots; few weakly weathered sub-rounded pebbles of siltstone and sandstone; distinct smooth boundary;

IIAhb  80 - 100 cm,
Dry; 10YR 4/1.5 (dry); 10YR 2/2 (moist); humic silt loam; strongly developed medium blocky structure; breaking to strongly developed fine and very fine blocky structure; slightly sticky; plastic; friable; moderately weak dry soil strength; very firm dry soil strength; few clay coatings on ped faces; common to many medium roots; no stones; indistinct smooth boundary;
IIwb  100 - 120 cm,
Dry; 10YR 5/3 (dry); 10YR 4/3 (moist); heavy silt loam; strongly developed medium and coarse blocky structure breaking to strongly developed fine and very fine blocky structure; sticky; plastic; friable; moderately firm dry soil soil and dry ped strengths; few thin clay coating on ped faces and lining pores; common medium roots; few weakly weathered sub-angular pebbles; indistinct smooth boundary;

IIBC  120 - 130 cm,
Dry; 2.5Y 7/3 - 6/3 (dry); 10YR 4/3 (moist); very fine sandy loam; moderately developed medium blocky structure breaking to moderately developed very fine and fine blocky structure; slightly sticky; plastic; friable; moderately firm dry soil and dry ped strengths; no coatings; few medium roots; common weakly weathered sub-angular and angular pebbles of siltstone and sandstone; distinct discontinuous boundary;

R   130 - 200 cm +,
Dry; 7.5Y 7/2; weakly weathered beds of sandstone 10 cm thickness overlies mudstone-siltstone;

Notes: Charcoal bits in IIAb dated at 750 + 70 years BP (Wk 1486), pottery sherds also in IIAb.

SOIL PROFILE 41
Location:- Syndendron, upper Leipskouki catchment, near P41, Tsifliki, Grevena
Exposure type:- Cutting, in roadside
Elevation:- 790 m
Soil taxonomy:- Entisol on alfisol
Common name:- Entisol on old red coll.
Erosion:- Gulllying & rill ubiquitous
Drainage:- Moderately permeable
Physiography:- Gently sloping toeslope, slope 10-150, aspect W
Parent material:- Recent dark greyish colluvium which buries an older Reddish brown soil

C   0 - 47 cm,
Dry; 5Y 8/2 (dry); 2.5Y 6/3 (moist); silt loam; very weakly developed medium blocky structure; slightly sticky; plastic; very friable; moderately weak dry soil and dry ped strengths; few very fine roots; common weakly weathered sub-angular pebbles of siltstone and sandstone; sharp discontinuous boundary;

IIb  47 - 110 cm,
Dry; 7.5YR 4/3 (dry); 7.5YR 4/3 (moist); clay loam; strongly developed medium blocky structure breaking to strongly developed very fine and fine blocky structure; sticky; plastic; moderately strong dry soil and dry ped strength; many clay coating on ped faces; common to many coarse roots; no stones; distinct discontinuous boundary;

IIbck 110 - 120 cm,
Dry; 5Y8/3 (dry); 2.5Y 4/2 (moist); many medium carbonate nodules; silt loam; massive breaking to very weakly developed medium blocky structure; sticky; plastic; very weak dry soil strength; no coatings; no roots; abundant moderately weathered angular pebbles and granules of siltstone and sandstone; indistinct smooth;

IIc  120 cm +,
Dry; 7.5Y 9/1 (dry); 5Y 6/3 (moist); many fine distinct veins of carbonate; silt; massive plus single grained; sticky; plastic; very weak dry soil strength; profuse moderately weathered angular pebbles and cobbles and granules sandstone plus siltstone;
SOIL PROFILE 42
Location:- Fossil gully fill in upper most catchment area, near Rodia, Grevena
Exposure type:- Cutting, road side  Elevation:- 790 m
Soil taxonomy:- Entisol on Alfisol  Common name:- Red Mediterranean
Erosion:- Gullying & rill common  Drainage:- Moderately permeable
Physiography:- Fossil gully fill, slope angle 120, aspect WNW,
Parent material:- Three phases of colluvium; very recent soil (<200 yrs) in which a modern
entisol has developed, 1st buried soil exhibiting mod development, a 2nd strongly
developed buried soil rests in a deep (<4m) bedrock hollow.

Aj  0-15 cm
2.5Y 5/3 dry; 2.5Y 4/3 moist; loamy fine sand; single grain; very friable; loose; loose dry ped
strength; many very fine roots; react HCl = weak; distinct wavy boundary;

Bj  15-40 cm
2.5Y 5/3 dry; 1Y 4/3 moist; gritty loamy fine sand; weak coarse blocky structure breaking to
moderate blocky structure; slightly sticky; slightly plastic; very friable; moderately weak;
moderately weak dry ped strength; common fine and medium roots; react HCl = moderate;
distinct smooth boundary;

Bu  40-70 cm
10YR 5/3 dry; 10YR 4/3 moist; gritty fine sandy loam; moderately developed medium plus
coarse blocky structure breaking to fine blocky structure; slightly sticky; plastic; friable;
moderately firm; moderately firm dry ped strength; common sub angular pebbles; react HCl =
moderate-strong; distinct smooth boundary;

IIBwb1  70-100 cm
10YR 5/3 to 10YR 3/3 moist; heavy silt loam; moderately developed medium blocky
structure breaking to strong fine blocky structure; sticky; very plastic; friable; few clay coats
on pores; react HCl = none; indistinct smooth boundary;

IIBwb2  100-145 cm
7.5YR 5/4 to 10YR 3/3 moist; heavy silt loam; strongly developed medium and coarse blocky
structure breaking to strong fine blocky structure; sticky; plastic; few clay coatings on peds;
react HCl = none; indistinct smooth boundary;

IIBwb  145-200 cm
7.5YR 4/3 to 7.5YR 3/4 moist; heavy silt loam; very strongly developed medium and coarse
blocky structure breaking to fine blocky structure; sticky; very plastic; friable; common clay
coatings on peds; few roots; react HCl = none; indistinct smooth boundary;

IIBtb1  200-245 cm
7.5YR 2/2; heavy silt loam; very strongly developed medium blocky structure breaking to
very strong fine blocky structure; sticky; plastic; friable; very firm; very firm dry ped
strength; common to many distinct clay and organic coatings on peds; few fine roots; react
HCl = none; indistinct smooth boundary;

IIIBC  295-350 cm
2.5Y 4/3; silt loam; weakly developed medium and coarse blocky structure; slightly sticky;
plastic; common clay and organic coatings of 7.5YR 3/2; react HCl = very weak; indistinct
smooth boundary;

IIIC  350-490 cm+
5Y 5/3 moist; loamy sand; massive; common weakly weathered angular cobbles and boulders
of sandstone; overlies bedrock at unknown depth below road cut; react HCl = very strong;
SOIL PROFILE 47
Location: Syndendron, down dirt road from spring near Paleokastro
Exposure type: Cutting in road section  Elevation: 720 m
Soil taxonomy: Inceptisol  Common name: Entisol on Inceptisol
Erosion: Gullying & rill ubiquitous  Drainage: Moderately permeable
Physiography: Slope of hill in moderately dissected hill country, slope 150
Parent material: Colluvial fill (Hellenistic) in bedrock hollow (fossil gully)

Aj 0 - 3 cm,
Slightly moist; 2.5Y 4/2 (as is); 2.5Y 4/2 (moist); fine sandy loam weakly developed very fine and fine blocky structure; slightly sticky; slightly plastic; very friable; very weak dry soil and dry ped strengths; many very fine and fine roots; no stones; indistinct smooth boundary;

Bj 3 - 22 cm,
Very slightly moist; 2.5Y5/2.5 (as is); 2.5Y 4/2 (moist); loamy sand; single grained plus weakly developed fine and medium blocky structure; slightly sticky; slightly plastic; very friable; very weak dry soil and dry ped strengths; no coatings; common fine and very fine roots; no stones; distinct smooth boundary;

BC 22 - 45 cm,
Very slightly moist; 2.5Y 6/2.5 (as is); 2.5Y 4/2 (moist); sandy loam; weak to moderately developed medium and coarse blocky structure; slightly sticky; slightly plastic; moderately firm dry soil and dry ped strengths; no coatings; few medium and coarse roots; few weakly weathered sub-angular pebbles and granules of sandstone; distinct smooth boundary;

IIAb 45 - 75 cm,
Dry; 2.5Y 5/2 (dry); 10YR 3/1 (moist); gritty silt loam; moderately developed medium and coarse blocky structure; slightly sticky; plastic; friable; moderately firm dry soil and dry ped strengths; few thin clay coatings on roots channels; few fine roots; common weakly weathered sub-angular pebbles and granules of sandstone; indistinct smooth boundary;

IIbb 75 - 120 cm,
Dry; 2.5Y 6/2 (dry); 10YR 3/1.5 (moist); gritty silt loam; moderately developed medium to coarse blocky structure breaking to moderately developed fine blocky structure; slightly sticky to sticky; plastic; friable; moderately firm dry soil and dry ped strengths; few thin clay coatings on roots channels; few fine roots; many weakly weathered sub-angular pebbles, cobbles and few granules; distinct smooth boundary;

III Colluvial unit A 120 - 195 cm,
Dry; 2.5Y 7/2 (dry); 2.5Y 4/2 (moist); gritty silt loam; massive to single grained breaking to weakly developed medium and coarse blocky structure; slightly sticky; slightly plastic to plastic; friable to firm; very firm dry soil strength; moderately firm dry ped strength; few thin clay coatings on root channels and pores; few fine roots; common weakly weathered sub-angular pebbles plus many weakly weathered sub-angular cobbles; distinct smooth boundary;

III Colluvial unit B 195 - 260 cm,
Dry; 2.5Y 7/2 (dry); 2.5Y 4/2 (moist); gritty very fine sandy loam; massive breaking to weakly developed coarse to very coarse blocky structure; slightly sticky; slightly plastic; friable; moderately firm dry soil strength; moderately weak dry ped strength; very few thin clay coatings on pores; common fine roots; common weakly weathered sub-angular pebble plus few cobbles; sharp wavy boundary; radiocarbon date = 2,190 + 70 years BP.
R 260 - 300 cm +,
Dry; mudstone bedrock; unweathered;

**Notes:** IIb very few fragments of pottery which are scrappy and look reworked.
Unit A has a continuous layer of sub-angular pebbles at it's base, Unit B has semi continuous layer of sub angular cobbles and is loaded with charcoal, bone and pottery. Also Unit A has a fine compact matrix with large sub-angular cobbles floating in matrix. Unit B has a lot of fine ash and charcoal which is causing discolouration, horizon has low bulk density is soft due to ash, also horizon contains much pottery.

**SOIL PROFILE 52**

| Location: | Leipsokouki upstream of Mega Sirini, opposite P51 on 9.6 m terrace |
| Exposure type: | Cutting in terraces edge |
| Elevation | 600 m |
| Soil taxonomy: | Vertic Xerochrept |
| Common name: | Dark brown colluvial |
| Erosion: | Stream bank cutting, creep |
| Drainage: | Moderately permeable |
| Physiography: | Surface of a Late Holocene terrace (9.6 m), slope angle 10, aspect S |
| Parent material: | Colluvial soil overlying a paleosol/vertisol on alluvium |

**Au1** 0 - 2 cm,
Dry; 10YR 4/2 (dry); 10YR 3/1 (moist); fine sandy loam; single grained plus weakly developed fine nut structure; non sticky; non plastic; loose; loose dry soil and dry ped strengths; un cemented; no coatings; abundant very fine roots; no stones; sharp smooth boundary;

**Au2** 2 - 40 cm,
Dry; 2.5Y 5/2 (dry); 10YR 4/2 (moist); silty clay loam; moderately developed medium blocky structure; slightly sticky; plastic; firm; very firm dry soil & dry ped strengths; no coatings; few fine roots; few mod. weathered rounded & sub-rounded granules; distinct smooth boundary;

**C** 40 - 60 cm,
Dry; 2.5Y 6.5/2 (dry); 2.5Y 5/2 (moist); gritty silt loam; weakly developed medium blocky structure; slightly sticky; plastic; friable; very firm dry soil and dry ped strength; un cemented; few fine roots; com mod. weathered rounded to sub-rounded granules; sharp smooth boundary;

**IIAb1** 60 - 95 cm,
Dry; 10YR 5/2 (dry); 10YR 4/2 (moist); silty clay; strongly developed coarse columnar structure; sticky; very plastic; firm; very firm dry soil & dry ped strengths; com slicken-sides; few fine roots; few weakly weathered subangular pebbles-cobbles (floating); distinct smooth boundary;

**IIAb2** 95 - 140 cm,
Dry; 10YR 4/1 and 10YR 4/2 (dry); 10YR 4/2 (moist); common fine distinct veinlets & coatings of carbonate; clay; strongly developed coarse blocky structure; very sticky; very plastic; firm; very firm dry soil & dry ped strengths; many slicken-sides; few fine roots; very few weakly and moderately weathered sub-angular & angular pebbles & cobbles; indistinct smooth boundary;

**IIck** 140 - 260 cm,
Dry; 5Y 7/2 (dry); 5Y 5/2 (moist); many fine distinct veinlets and nodules of carbonate; silt; massive; slightly sticky; plastic; friable; moderately firm dry soil and dry ped strengths; very weakly cemented; no roots; few layers of abundant weakly plus moderately weathered rounded and sub-rounded granules (all.); sharp smooth boundary;
IIIAb 260 - 285 cm,
Dry; 2.5Y 6/2.5 (dry); 2.5Y 5/2.5 (moist); common fine distinct veinlets and nodules of carbonate; fine sandy clay loam; moderately to strongly developed prismatic structure (maybe related to cracking); sticky; very plastic; firm; moderately strong dry soil and dry ped strengths; very weakly cemented; no stones; no roots; distinct smooth boundary;

IIIC 285 cm + (terrace is 9.6 m high),
Dry; 5Y 7/3 (dry); 5Y 5/3 (moist); many fine veinlets & nods of carbonate; fine sandy loam; massive breaking to single grained; v. slightly sticky; plastic; friable; very firm dry soil strength; very weakly cemented CaCO3; few layers of abundant weakly + moderately weathered rounded-subrounded granules;

Notes: Whole profile has a moderate - strong reaction to HCl. 2-2.6 m few red specks of pottery. C2 contains charcoal rich layers near base of section. At 485 cm discontinuous charcoal layer occurs (sampled for date, 2,330 + 70 years, Wk 1579). Piece of pottery, at base of section, coated in CaCO3. 2-3 m handmade body sherds un-diagnostic. 140 - 260 wheel made Historic pot sherds

SOIL PROFILE 59
Location: Mega Sirini, near the new spring, upstream of Mega Sirini
Exposure type: Cutting made by new spring
Soil taxonomy: Xerorthent on pelloxerert
Common name: Young colluvial soil
Erosion: Debris slide-flow
Drainage: Moderately permeable
Physiography: Hill slope, slope angle 110, aspect SW
Parent material: Thick 2 m colluvial unit over buried soil which is dated to 4,400 ± 60 years.

Aj 0 - 3 cm,
Dry; 2.5Y 5/3 (dry); 10YR 4/2 (moist); common very fine faint carbonate nodules; fine sandy loam; weakly developed granular structure; non sticky; very slightly plastic; very friable; very weak dry soil and dry ped strengths; uncemented; abundant very fine and fine roots; react to 10% HCl = strong; sharp wavy boundary;

IICA1 3 - 40 cm,
Dry; 2.5Y 6/3 (dry); 2.5Y 5/3 (moist); common very fine faint carbonate nodules; silt loam; weakly developed fine and medium blocky structure; very slightly sticky; slightly plastic; very friable; very weak dry soil and dry ped strengths; uncemented; very few thin clay coatings lining pores and root channels; common fine roots; few weakly to moderately weathered angular pebbles of sandstone; react to 10% HCl = strong; indistinct wavy boundary;

IICA2 40 - 220 cm,
Dry; 2.5Y 6/3 (dry); 2.5Y 5/3 (moist); few very fine faint carbonate nodules; silt loam; weakly developed medium and coarse blocky structure; very slightly sticky; slightly plastic; very friable; very weak dry soil and dry ped strengths; uncemented; common fine roots; few weakly to moderately weathered angular pebbles of sandstone; react to 10% HCl = strong; diffuse boundary;

IIC 220 - 255 cm,
Dry; 2.5Y 7/2 (dry); 2.5Y 6/3 (moist); few very thin faint coatings of carbonate; silt loam; massive; very slightly sticky; slightly plastic; very friable to loose; very weak dry soil strength; uncemented; few medium roots; few moderately weathered angular pebbles of sandstone; react HCl very strong; sharp wavy boundary;
IIIAb 255 - 350 cm,
Dry; 10YR 4/2 (dry); 10YR 4/2 (moist); common fine distinct carbonate coatings and veinlets; silty clay; strongly developed medium blocky structure; sticky; very plastic; firm; moderately strong dry soil and dry ped strengths; many sicken-sides; no roots; no stones; react to 10% HCl = moderate; indistinct irregular boundary;

IIIA/C 350 - 365 cm,
Dry; 10YR 5/2 and 2.5Y 6/2 (dry); 10YR 5/2 (moist); many fine and medium distinct nods of CaCO3; silty clay loam; moderately developed medium blocky structure; sticky; plastic; firm; very firm dry soil and dry ped strengths; uncemented; no roots; no stones; diffuse boundary;

IIIC 365 - 390 cm,
Dry; 5Y 9/1 (dry); many carbonate nodules and veinlets; massive; distinct smooth boundary;

IVAb 390 - 400 cm, Very thin paleosol; not described,

Alluvium 400 cm +, White layered gravels and granules

Notes: No pottery seen, but a lot of charcoal, two samples for radio carbon dating taken one in IIIAb, and one in alluvium. Main buried soil radiocarbon dated at 4,400 ± 60 years (Wk 1582).

SOIL PROFILE 60
Location:- Opposite Mega Sirini, near to P38 at head of main gully
Exposure type:- Cutting at head of deep gully Elevation- 660 m
Soil taxonomy:- Pelloxerert Common name:- Dark swelling soil
Erosion:- Headward migrating gully Drainage:- Slowly permeable
Physiography:- Intermediate sloping strath, humocky micro relief slope 7°, aspect NE
Parent material:- Soil probably developed in colluvium, but many sub-rounded gravels andstones at base of profiles (1-1.9 m), this lower gravel probably alluvial.

Au1 0 - 3 cm,
Dry; 10YR 3.5/1 (dry); 10YR 3/1 (moist); no carbonate; heavy silt loam; strongly developed fine and medium granular structure; slightly sticky; plastic; friable; very weak dry soil strength; moderately weak dry ped strength; uncemented; many fine roots; no stones; react HCl = none; indistinct smooth boundary;

Au2 3 - 28 cm,
Dry; 10YR 3/1 (dry); 10YR 3/1 (moist); no carbonate; silty clay; strongly developed medium nut structure breaking to strongly developed fine nut structure; very sticky; very plastic; friable; very firm dry soil and dry ped strengths; uncemented; no coatings; common fine roots; no stones; indistinct smooth boundary;

Au3 28 - 70 cm,
Dry; 10YR 2.5/1 (dry); 10YR 2/1 (moist); no carbonate; silty clay; strongly developed very coarse blocky structure; very sticky; very plastic; friable; moderately strong dry soil and dry ped strengths; uncemented; common sicken-sides; few fine roots; no stones; indistinct smooth boundary;

Au4 70 - 98 cm,
Dry; 2.5Y 4/2 and 10YR 4/1 in cracks (dry); 2.5Y 4/3 (moist); very few very fine faint carbonate nodules; clay; moderately developed very coarse blocky structure; very sticky; very plastic; very firm; very strong dry soil and dry ped strength; uncemented; hard penetration
resistance; common slicken-sides; few medium organic coatings of 10YR 3/1 in cracks; few fine roots; no stones; react HCl = slight; indistinct smooth boundary; (two pieces of pottery in horizon)

**A/C 98 - 150 cm,**
Dry; 2.5Y 5/3 and white (dry); 2.5Y 4/3 (moist); common fine distinct veinlets and some nodules; clay; moderately developed medium blocky structure; very sticky; very plastic; friable; moderately firm dry soil and dry ped strength; uncemented; hard penetration resistance; few fine roots; few moderately and strongly weathered rounded and sub-rounded cobbles of sandstone; react HCl = strong; indistinct smooth boundary;

**C/Ak 150 - 300 cm,**
Dry; 2.5Y 6/4 and white (dry); 2.5Y 6/3 (moist); many fine distinct coatings, veinlets and some nodules of carbonate; silty clay loam; weakly developed medium blocky structure; very sticky; plastic; very friable; moderately weak dry soil strength; moderately firm dry ped strength; very few fine roots; common moderately and strongly weathered cobbles of sandstone; react HCl = very strong; diffuse smooth boundary;

**Ck 300 cm +,**
Dry; 5Y 8/2 and white (dry); profuse medium distinct nodules, veins and coatings; no roots; many moderately and strongly weathered rounded and sub-rounded cobbles of sandstone; react HCl = very strong;

---

**SOIL PROFILE 61**

**Location:** Mega Sirini, up slope and behind second major gully near Agios Hilias

**Exposure type:** Cutting in road side  
**Elevation:** 680 m

**Soil taxonomy:** Inceptisol over vertisol  
**Common name:** Young colluvial soil

**Erosion:** Headward migrating gully  
**Drainage:** Moderately permeable

**Physiography:** Gentle hill slope, angle 120, aspect NE

**Parent material:** Youngish colluvial soil on top of chromic vertisol

**Ah 0 - 15 cm,**
Dry; 10YR 4/2 (dry); 10YR 3/1 (moist); very few very fine faint nodules of carbonate; silty clay loam; strongly developed very fine nut and granular structure; sticky; plastic; friable; very weak dry soil strength; moderately firm dry ped strength; uncemented; many fine roots; few moderately weathered sub-rounded gravels of sandstone and granite; react HCl = weak; distinct irregular boundary;

**A/C 15 - 35 cm,**
Slightly moist; 2.5Y 6/2 (dry); 2.5Y 4/3 (moist); many fine faint nodules of carbonate; silt loam; moderately developed very fine and fine nut structure; non sticky; plastic; very friable; very weak dry soil and dry ped strength; uncemented; few fine roots; few moderately weathered sub-rounded gravels of sandstone and granite; react HCl = strong; distinct smooth boundary;

**IIAb 35 - 58 cm,**
Slightly moist; 7.5YR 4/3 (dry); 10YR 3/2.5 (moist); common fine (2-3 mm) distinct nodules of carbonate; clay; strongly developed coarse blocky structure; very sticky; very plastic; friable; moderately firm dry soil and dry ped strength; uncemented; common slicken-sides; few medium clay coatings on gravels; common medium and coarse roots; no stones; react HCl = moderate; indistinct irregular boundary;

**IIA/C 58 - 95 cm,**
Slightly moist; 10YR 5/3 and white (dry); 10YR 3/2 and 10YR 8/2 (moist); 2.5Y 5/3 (rubbed); profuse fine and medium distinct veins and nodules of carbonate; silty clay loam; massive; very sticky; very plastic; friable; moderately weak dry soil strength; uncemented; few medium roots; few moderately weathered sub-angular pebbles of sandstone and granite; react to HCl = strong; diffuse boundary;

**C/A 95 - 110 cm +,**
Slightly sticky; 2.5Y 5/3 and 2.5Y 4/2 (moist); profuse fine and medium distinct veins and nodules of carbonate; silty clay loam; massive; very sticky; very plastic; friable; moderately weak dry soil strength; uncemented; few moderately weathered sub-angular pebbles of sandstone and granite; react to HCl = strong;

**Notes:** IIAb strongly cracked 2-4 mm wide forming very coarse blocky structure. No pot sherds.

**SOIL PROFILE 76**

| Location: | Upper Leipsokouki catchment |
| Exposure type: | Cutting |
| Elevation: | 860 m |
| Soil taxonomy: | Inceptisol-alfisol |
| Common name: | Reddish-brown soil |
| Erosion: | Strong sheet and rill nearby |
| Drainage: | Well |
| Physiography: | Slope of hill in moderately dissected hill country, 180, aspect S |
| Parent material: | Soil coll. (2.2 m) on rock colluvium (>2 m) in bedrock depression, >4 m. |

**Aj 0 - 6 cm,**
Dry; 10YR 2/2 (dry); 10YR 2/1 (moist); humic loamy fine sand; weakly developed very fine granular structure plus single grained; non to slightly sticky; loose; very weak dry soil and dry ped strengths; uncemented; many very fine and fine roots; no stones; react to HCl = slight; distinct smooth boundary;

**Bj 6 - 22 cm,**
Dry; 1Y 5/4 to 10YR 5/4 (dry); 10YR 4/3 (moist); very fine sandy loam; moderately developed medium blocky structure plus moderately developed fine nut structure; slightly sticky; plastic; friable; very firm dry soil and dry ped strengths; uncemented; very few faint clay coatings lining pores; common fine roots; few weakly weathered angular pebbles of sandstone; react to HCl = moderate; distinct smooth boundary;

**IIBb1 22 - 80 cm,**
Dry; 7.5YR 5/5 (dry); 7.5YR 4/4 (moist); fine sandy clay loam; strongly developed very coarse blocky structure breaking to strongly developed medium and fine blocky structure; sticky; plastic; friable; moderately strong dry soil and dry ped strengths; uncemented; many distinct clay coatings lining pores, few lining ped faces; few fine and medium roots; very few strongly weathered angular pebbles of sandstone; react to HCl = none; diffuse smooth boundary;

**IIBb2 80 - 150 cm,**
Dry; 10YR 5/5 (dry); 7.5YR 4/3 (moist); fine sandy clay loam; strongly developed very coarse blocky structure breaking to strongly developed medium and fine blocky structure; sticky; plastic; friable; very firm dry soil and dry ped strengths; uncemented; common distinct clay coatings lining pores, few lining ped faces; few fine and medium roots; very few strongly weathered angular pebbles of sandstone; react to HCl = none; diffuse smooth boundary;

**IIBb3 150 - 215 cm,**
Dry; 10YR 5/4 (dry); 7.5YR 4/4 (moist); fine sandy clay loam; strongly developed very coarse blocky structure plus strongly developed medium blocky structure; sticky; plastic;
frangible; very firm dry soil and dry ped strengths; uncemented; few faint clay coatings lining pores; few fine and medium roots; no stones; react to HCl = none; distinct smooth boundary;

IIIc 215 - 330 cm +,
Dry; 2.5Y 6/4 and white (dry); 1Y 5/4 (moist); many fine distinct filaments and channel fillings of carbonate; fine sandy loam; massive; moderately strong dry soil strength; weakly cemented; few medium roots; common (many in places) moderately weathered angular pebbles and cobbles of sandstone; react to HCl = very strong;

**SOIL PROFILE 77**

<table>
<thead>
<tr>
<th>Location:</th>
<th>Road from Rodia to Syndendron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure type:</td>
<td>Cutting</td>
</tr>
<tr>
<td>Soil taxonomy:</td>
<td>Pelloxerert</td>
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<tr>
<td>Common name:-</td>
<td>Black swelling clay</td>
</tr>
<tr>
<td>Erosion:-</td>
<td>Creep, sheet, rill and gullying</td>
</tr>
<tr>
<td>Drainage:-</td>
<td>Moderate</td>
</tr>
<tr>
<td>Physiography:-</td>
<td>Slope depression in dissected hill country, slope angle 11°, aspect N NW</td>
</tr>
<tr>
<td>Parent material:-</td>
<td>3.5 m of very dark brown soil colluvium containing Middle Bronze Age pot sherds resting in a bedrock hollow.</td>
</tr>
</tbody>
</table>

**AC 0 - 20 cm,**
Dry; 5Y 7/2 (dry); 2.5Y 5/3 (moist); com fine faint nodules of carbonate; silt loam; weakly developed medium + coarse granular structure; sticky; plastic; very weak dry soil & dry ped strengths; com. very fine-fine roots; few weakly weathered angular pebbles of mudstone; react to HCl = strong; distinct smooth boundary;

**IIAb1 20 - 110 cm,**
Slightly moist; 10YR 3/2 (dry); 10YR 2/2 (moist); few fine faint nodules of carbonate; silty clay loam; strongly developed very coarse blocky structure breaking to moderately developed medium and coarse blocky structure; very sticky; very plastic; friable; moderately firm dry soil strength; very firm dry ped strength; uncemented; common faint clay coatings lining pores; very few very fine and fine roots; no stones; react to HCl = slight; diffuse smooth boundary;

**IIAb2 110 - 180 cm,**
Slightly moist; 10YR 2/2 and 10YR 4/3 (dry); 10YR 2/2 (moist); clay to silty clay; strongly developed very coarse blocky structure breaking to strongly developed fine and medium platy structure; very sticky; very plastic; friable; very firm dry soil strength; moderately strong dry ped strength; uncemented; common faint clay coatings lining pores; many slicken-sides; very few very fine and fine roots; no stones; react to HCl = none; diffuse smooth boundary;

**IIAb3 180 - 250 cm,**
Slightly moist; 10YR 3/2 (dry); 7.5YR 3/2 (moist); clay; strongly developed very coarse blocky structure breaking to strongly medium + coarse blocky structure; very sticky; very plastic; firm; very firm dry soil strength; moderately strong dry ped strength; uncemented; many distinct clay coatings lining pores; many slicken-side; very few very fine and fine roots; no stones; react to HCl = none; diffuse smooth boundary;

**IIAb4 250 - 300 cm,**
Slightly moist; 7.5YR 3/2 (dry); 7.5YR 3/2 (moist); clay; strongly developed coarse blocky structure breaking to strongly developed fine and medium blocky structure; very sticky; very plastic; firm; very firm dry soil and dry ped strengths; uncemented; many distinct clay coatings lining pores; very few very fine and fine roots; no stones; react to HCl = none; distinct smooth boundary;
IIA/C 300 - 340 cm,
Slightly moist; 2.5Y 6/4 and 10YR 4/3 (dry); 2.5Y 5/4 (moist); silty clay loam; moderately
developed coarse blocky structure breaking to moderately developed fine and medium blocky
structure; very sticky; very plastic; friable; moderately firm dry soil and dry ped strengths;
uncemented; few faint clay coatings lining pores; very few very fine and fine roots; no stones;
react to HCl = none; distinct smooth boundary;

IIC 340 - 380 cm,
Slightly moist; 2.5Y 6/3 (dry); 2.5Y 4/3 (moist); silty clay loam; weakly developed medium
and coarse blocky structure; very sticky; very plastic; moderately weak dry soil and dry ped
strengths; uncemented; very few very fine roots; no stones; react to HCl = none; distinct
smooth boundary;

R 380 - 600 cm + Mudstone bedrock in situ;

Notes: Early Bronze age pot sherds throughout upper 2 m.

SOIL PROFILE 81
Location:- Above Tsifliki on Syndendron - Rodia road
Exposure type:- Cutting Elevation:- 850 m
Soil taxonomy:- Alfisol Common name:- Red clay
Erosion:- Sheet and rill erosion, + gully Drainage:- Well
Physiography:- Crest of hill in moderately dissected hill country, slope angle 16°, aspect N
Parent material:- Soil originally probably colluvial, or insitu weathering to 2 m (?)
B/Ck  115 - 135 cm,
Slightly moist; 7.5YR 3/2 and 2.5Y 6/4 (dry); 5YR 4/4 (rubbed, moist); common to many fine distinct powdery nodules of carbonate; silty clay loam; moderately developed medium and coarse blocky structure; sticky; plastic; friable; moderately weak dry soil strength; moderately firm dry ped strength; uncemented; few faint clay coatings lining pores; few fine and medium roots; very few moderately weathered sub angular pebbles of sandstone and mudstone; react to HCl = moderate; indistinct irregular boundary;

Ck  135 - 145 cm,
Slightly moist; 5Y 8/2 and 10YR 7/3 and 10YR 3/4 mix (dry); 10YR 5/6  (rubbed, moist); common to many fine and medium distinct powdery nodules of carbonate; silt loam; weakly developed medium and coarse blocky structure; sticky; plastic; friable; very weak dry soil strength; moderately weak dry ped strength; uncemented; no roots; few moderately weathered subangular pebbles of sandstone and mudstone; react to HCl = ; indistinct irregular boundary;

C(k)  145 - 200 cm,
Slightly moist; 2.5Y 6/4 and 10YR 8/1 mix (dry); 2.5Y 6/3 (moist); common fine distinct powdery nodules of carbonate; silt loam; massive breaking to very weakly developed medium blocky structure; slightly sticky; plastic; very friable; very weak dry soil and dry ped strengths; uncemented; no roots; few moderately weathered sub angular pebbles of sandstone and mudstone; react to HCl = strong; distinct smooth boundary;

R  200 cm +,  Dry; 7.5Y 9/2 (dry); 7.5Y 7/2 (moist); silt; massive; mudstone bedrock;
Appendix 3 Paleomagnetic data from Doyle (1990)

Results of paleomagnetic measurements and stepwise demagnetisation in alternating field.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Sample No.</th>
<th>Intensity (mA/m)</th>
<th>Declination</th>
<th>Inclination</th>
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</table>
Table 8.1  Alluvial units in the Leipsokouki valley

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>$^{14}$C years BP</th>
<th>Calibrated yrs BP</th>
<th>Archaeological artefacts (Wilkie and Savina 1992)</th>
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</thead>
<tbody>
<tr>
<td>Leipsokouki alluvium</td>
<td>C18, Capped by calc. coll.</td>
<td>Modern (C18)</td>
<td>&gt;140 ± 130</td>
<td>Probably Hellenistic, Roman, Ottoman &amp; late Early Bronze</td>
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<tr>
<td></td>
<td>P29, P31, P33, P50, P55</td>
<td></td>
<td></td>
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</table>

This is a very recent channel and over-bank deposit with young and incipient soils (entisols). The alluvium forms a 1 - 3 m thick deposit on the valley floor comprised of a gravelly lower part (channel type) and a silt – fine sandy upper part (over-bank type). The gravelly channel deposits contain sherds from Bronze Age to the Ottoman period indicating the alluvium is <0.5 kyr BP. The soils which form in the over-bank deposits have only weak – moderately developed topsoils and lack “colour” B2 or cambic horizons. The alluvium may be capped by recent calcareous colluvium if deposited close to valley slopes, e.g., C18 as dated above.

Sirini alluvium (A, B & C)  Modern incipient soil profile not dated, often formed from colluvium

Sirini C, 2.1 – 1.7 kyr BP  C16a, Greyish calc. colluvium  1,804 ± 47  1,735 ± 135
                            C4a, Upper colluvial soil      2,047 ± 56  2,090 ± 60
Sirini B, 3.1 – 2.1 kyr BP  C4b, Sirini B alluvium  2,946 ± 146  3,100 ± 350
                            P52, Sirini B alluvium          2,330 ± 70  2,450 ± 300
                            C3a, Sirini B alluvium          2,785 ± 128  3,025 ± 325
                            C16b, Coll. soil on Sirini B    2,302 ± 47  2,295 ± 145
Sirini A, 4.2 - <3.1 kyr BP  C14, Sirini A alluvium  3,797 ± 165  4,150 ± 500

This alluvial fill is quite distinct in the valley and forms a 4-9 m thick alluvial fans, typically where side-streams meet the main valley. They are composed of alternating channel and over-bank deposits with one key soil developing ca. 4 – 3.1 kyr BP. This buried soil separates the Sirini alluvium into Sirini A ca. 4.2 - 3.1 cal kyr BP and the Sirini B ca. 3.1 – 2.1 kyr BP. Clearly this alluvia began deposition in the Early-Middle Bronze Age and then stabilised allowing a brief period of soil formation before recommencing alluvial deposition until about 2.1 kyr BP. A later phase of alluviation occurs at C16 with 1.4 m of deposition between 2.1 – 1.7 kyr BP (Sirini C).

Amygdalies alluvium the colluvial capping

Alluvium 5.9 – 4.7 kyr BP  C8d, Upper gravelly colluvium  3,967 ± 185  4,375 ± 525
                            C8c, 1st buried alluvial soil     4,143 ± 47  4,685 ± 165
                            C8b, 2nd buried alluvial soil     4,707 ± 159  5,300 ± 450
                            C8a, Basal alluvium              5,141 ± 184  5,875 ± 425

This alluvial and colluvial section is described at site C8 in the Amygdalotikos tributary. It is very tightly constrained and represents a series of small scale alluvial aggradation events which are followed by short (500 years) periods of soil formation before further alluvial deposition. The alluvial events are associated with hill slope erosion as shown by lateral facies changes from alluvium to colluvium with increasing proximity to the adjacent slopes, particularly after 5.3 kyr BP. The site was buried by over 2 m of gravelly colluvium after 4.4 kyr BP. The main alluvial deposit is 5.9 – 4.7 cal kyr BP.
The Syndendron alluvium forms a substantial silty to fine sandy deposit in the Leipsokouki valley which varies from ca. 2 m to more than 11 m thick. It is separated by a 9.3 kyr BP paleosol into two parts - Syndendron A and B. The Syndendron A is composed of fine sands with common grit layers at its base and well-stratified silty to fine sandy alluvium in the upper part. The upper part of the Syndendron A alluvium is typically capped by a dark buried silty clay loam colluvial soil dated to 8.1 – 9.9 kyr BP. At some sites e.g., P37 about 1 m of fine textured alluvium caps a 9.4 kyr BP paleosol – this overlying alluvium is termed Syndendron B. At site C17 0.2 m of fine alluvium caps the paleosol formed above the Syndendron A – this is also termed Syndendron B. Very dark brown pedogenic colluvial materials cap most Syndendron alluvial sections. These dark pedogenic colluvia appear to have been deposited in at least three and commonly four phases each identified by separate soil morphological characteristics at ca. 9.9 – 9.4, 8.0 – 7.5, 5.3 – 4.3 and 3.9 – 2.7 kyr BP with lighter coloured, more recent, calcareous colluvium at the surface at ca. 2.2 – 1.4 and 0.7 – 0.4 kyr BP.

Table 8.2 Slope deposits in the Leipsokouki valley

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>14C years BP</th>
<th>Calibrated yrs BP</th>
<th>Archaeological artefacts (Wilkie and Savina 1992)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very recent calc. coll.</strong></td>
<td>P71, P4, P23, C12, C18</td>
<td>Modern</td>
<td>140 ± 130</td>
<td>Ottoman, Turkish glass, roof tiles, Post Byzantine</td>
</tr>
<tr>
<td><strong>Recent dark greyish brown and brown colluvial soils</strong></td>
<td>C2, Dark grey soil colluvium</td>
<td>312 ± 38</td>
<td>380 ± 90</td>
<td>Significant fire and erosion of landscape</td>
</tr>
<tr>
<td></td>
<td>P40, Thin buried colluvial soil</td>
<td>750 ± 70</td>
<td>675 ± 125</td>
<td>Significant fire in landscape</td>
</tr>
</tbody>
</table>

This unit is characterised by its very pale grey colour and highly calcareous nature. The deposits are very recent and may relate to current active erosion but certainly in some part to the period of modern mechanised agricultural and roading. These materials typically lack the development of a distinct topsoil and so are extremely young.
Unit Sites/material $^{14}$C years BP Calibrated yrs BP Archaeological artefacts (Wilkie and Savina 1992)

**Thick dark greyish, partly leached calcareous colluvia**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>$^{14}$C years BP</th>
<th>Calibrated yrs BP</th>
<th>Roman &amp; Byzantine sherds in upper 1 m, Hellenistic below 1 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>P36</td>
<td>Greyish calcareous coll.</td>
<td>$1,410 \pm 50$</td>
<td>$1,390 \pm 130$</td>
<td></td>
</tr>
<tr>
<td>C16a</td>
<td>Greyish calcareous coll.</td>
<td>$1,804 \pm 47$</td>
<td>$1,735 \pm 135$</td>
<td></td>
</tr>
<tr>
<td>P47</td>
<td>Greyish calcareous coll.</td>
<td>$2,190 \pm 70$</td>
<td>$2,175 \pm 175$</td>
<td></td>
</tr>
<tr>
<td>C16b</td>
<td>Dk. soil coll. on Sirini all.</td>
<td>$2,502 \pm 47$</td>
<td>$2,295 \pm 145$</td>
<td></td>
</tr>
</tbody>
</table>

**Very dark brown, non-calcareous, pedogenic colluvia**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>$^{14}$C years BP</th>
<th>Calibrated yrs BP</th>
<th>Iron Age or Early-Middle Bronze Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>P11</td>
<td>Dk colluvium</td>
<td>$2,650 \pm 200$</td>
<td>$2,750 \pm 600$</td>
<td>Early Iron Age</td>
</tr>
<tr>
<td>P58</td>
<td>Dk. colluvium</td>
<td>Not dated</td>
<td>$&lt; 3.9 – 2.7$ kyr</td>
<td>Iron Age or Early-Middle Bronze Age</td>
</tr>
<tr>
<td>P77</td>
<td>Dk colluvium</td>
<td>Not dated</td>
<td>$&lt; 3.9$ kyr</td>
<td>All Middle Bronze Age (single period)</td>
</tr>
<tr>
<td>C8c-d</td>
<td>Stony reddish coll.</td>
<td>$&lt; 4.7$ kyr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C11c</td>
<td>Dk colluvium</td>
<td>$4,429 \pm 138$</td>
<td>$5,050 \pm 450$</td>
<td></td>
</tr>
<tr>
<td>P59</td>
<td>Dk colluvium</td>
<td>$4,400 \pm 60$</td>
<td>$5,065 \pm 225$</td>
<td></td>
</tr>
<tr>
<td>C12c</td>
<td>Dk colluvium</td>
<td>$6,627 \pm 142$</td>
<td>$7,500 \pm 250$</td>
<td></td>
</tr>
<tr>
<td>C17c</td>
<td>Dk colluvium</td>
<td>$7,218 \pm 47$</td>
<td>$8,050 \pm 110$</td>
<td></td>
</tr>
<tr>
<td>C9c</td>
<td>Dk. colluvium</td>
<td>$7,303 \pm 57$</td>
<td>$8,085 \pm 115$</td>
<td></td>
</tr>
<tr>
<td>P37</td>
<td>Dk paleosol on Synd. A</td>
<td>$8,380 \pm 170$</td>
<td>$9,350 \pm 600$</td>
<td>Grinding stone (note alluvium above the is called Syndendron B)</td>
</tr>
<tr>
<td>C12b</td>
<td>Dk. coll on Synd. B.</td>
<td>$8,816 \pm 58$</td>
<td>$9,900 \pm 300$</td>
<td></td>
</tr>
</tbody>
</table>

**Debris flow deposits**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Sites/material</th>
<th>$^{14}$C years BP</th>
<th>Calibrated yrs BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Debris flow with soil pieces</td>
<td>$5,710 \pm 142$</td>
<td>$6,550 \pm 350$</td>
</tr>
<tr>
<td>C11</td>
<td>Calcareous stony debris</td>
<td>$6,605 \pm 99$</td>
<td>$7,490 \pm 180$</td>
</tr>
<tr>
<td>P76</td>
<td>Stony compact debris</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These materials are typically pedogenic in nature – they are however over-thickened gully or depression accumulations of soil like colluvium. They lack a “colour” B2 horizons but would meet the requirement of a “structure” B2. However, the deposits are clearly the redeposited remains of previous soil materials derived from up slope e.g., dark vertisols and mollisols leading to inherited pedogenic character. Overall the sections lack clear soil horizon differentiation. However, carbonate has been leached from upper 0.5m of most dark pedogenic colluvia, with distinct increases in carbonate in the base of the gully fills. The materials must have moved by creep and colluvial processes rather than by slope wash so as to preserve the pedogenic characteristics.

(Doyle 2004)